S. Hrg. 100-993

COSMOS 1900 AND THE FUTURE OF SPACE NUCLEAR POWER

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MAR 23 1989

HEARING

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDREDTH CONGRESS

SECOND SESSION

ON

COSMOS 1900 AND THE FUTURE OF SPACE NUCLEAR POWER

SEPTEMBER 13, 1988

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COSMOS 1900 AND THE FUTURE OF SPACE NUCLEAR POWER

TUESDAY, SEPTEMBER 13, 1988

U.S. Senate,
Committee on Energy and Natural Resources,
Washington, DC.

The committee met, pursuant to notice, at 9:38 a.m., in room SD-366, Dirksen Senate Office Building, Hon. J. Bennett Johnston, chairman, presiding.

OPENING STATEMENT OF HON. J. BENNETT JOHNSTON, U.S. SENATOR FROM LOUISIANA

The Chairman. Good morning. Today the Committee will hear testimony on Cosmos 1900 and the future of space nuclear power.

As we sit here today, a Soviet military satellite is barely hanging in earth orbit, and on the verge of falling from the sky.

Unfortunately, this satellite, called Cosmos 1900, contains a hot nuclear reactor with something like 100 pounds of uranium on board. At least twice before similar Soviet satellites with nuclear reactors, for electrical power supply, have fallen from orbit. In 1977 such a satellite strewed highly radioactive fragments over a wide area of rural Canada.

We do not know with any precision where or when Cosmos 1900 will come to earth, although I hope this hearing will give us the best available information.

The Soviets had recently announced that this satellite, with which they have lost radio contact, has new automatic safety features, which will prevent the reactor from falling to earth. We will soon find out if the automatic switches work, if the booster rocket ignites and the reactor is guided into safe orbit.

Last week the Soviets nearly had two cosmonauts entombed in space because of faulty automatic devices. It was only because they overrode those automatic devices that they were able to bring the cosmonauts safety to earth.

This hearing is intended to give the public the best information that is available about the fate of Cosmos 1900. I believe that the facts will tend to calm the public rather than alarm them. But I also think the facts will tend to anger them.

The Soviets should be condemned for periodically creating a situation in which people around the world must wonder if pieces of a nuclear reactor will rain down upon them. Soviet sloppiness with the nuclear reactor at Chernobyl was inexcusable. Sloppiness with nuclear reactors in space is intolerable.

Unfortunately, the fallout of fear from Chernobyl affected our own nuclear industry most undeservedly.

I do not want to see this happen with Cosmos 1900 and the U.S. efforts to develop a nuclear reactor for use in space, which won't fly until the mid-1990s, if then.

In the wake of Cosmos 1900, some editorialists around the country have already called for a ban on all nuclear reactors in space. To me that presumes that we can not make intelligent decisions about how we use technology, so we must throw the good out with the bad.

And this hearing will demonstrate that there are some very attractive far-term potential applications of space nuclear reactors, applications which I do not believe any of us are wise enough today to dismiss before the 21st century even begins.

There is also a marked contrast between the current Soviet safety practices and those we will follow with space nuclear reactors. This is not to say that there is no reason for concern.

We need to find some way to affect Soviet practices with space nuclear reactors. And we have to think very carefully about moving in the direction which will lead the Soviets into situations which invite carelessness.

For example, few Americans realize that a Star Wars deployment of lasers and other directed energy weapons in space may require dozens, perhaps 100 or more nuclear reactors in space to power them and other accessories.

Given the history of Soviet sloppiness with Chernobyl, and Cosmos 1900, I would shutter to think that they would match our SDI deployment with a constellation of Chernobyls in space.

Our witnesses are well-equipped to discuss these points and I look forward to hearing their testimony.

Senator Wallop, before we have our first witness, I welcome you and ask for your comments.

Senator WALLOP. Thank you, Mr. Chairman. I have no opening statement. But I would be astonished if anybody at this table were able to tell us about a Chernobyl in space or anything even remotely resembling it.

The CHAIRMAN. Well, I hope they did not put a Chernobyl in space, but at least they have got Cosmos 1900 and we know it is there.

[A prepared statement from Senator McClure submitted for the record follows:]

OPENING STATEMENT - SENATOR JAMES A. McCLURE
SEPTEMBER 13, 1988 HEARING ON
COSMOS 1900

Good morning. I am grateful to the Chairman for his keen interest in the subject of space nuclear reactors, and hence the scheduling of this hearing.

For too long the subject of space nuclear power has gone unattended. Speaking for myself, the safe use of nuclear power in space applications has a tremendous potential that deserves a much higher profile in the public sector and in the minds of the customers who must ultimately tap this resource to energize their missions. It is my firm belief that nuclear power will play a key role in future space missions of NASA, and in meeting the surveillance and strategic requirements of the Department of Defense.

For those who would thwart the deployment of space nuclear systems for defense-related orbital applications, I would caution the public with these remarks:

- For many years now, the Soviets have relied heavily on nuclear reactors to power sophisticated radar surveillance systems for which we currently have no counterpart.
- The fact that the Soviet safety practices with respect to space nuclear systems is deficient by our standards does not mean that our program cannot meet the highest safety standards, nor does it mean that we cannot effect a change in the Soviet safety philosophy via international agreements.
- Be cautious of the opponent's misuse of data relating to the consequences of nuclear systems re-entry, and instead look at

the real facts to date that indicate negligible environmental or health effects.

I hope that this hearing will bring a greater understanding and appreciation of the potential uses of space nuclear power, so that the program development under the guardianship of the Department of Energy can be sustained, nurtured, and supported with a high degree of confidence by its customers and by the general public.

The CHAIRMAN. I want to begin with a panel composed of Dennis A. Bitz, Assistant Secretary for Space and Defense Power Systems, the Office of Nuclear Energy of the Department of Energy, Col. Henry G. Culbertson III, Chief, U.S. Space Control Operations Division of the U.S. Space Command from Colorado Springs, Col. George M. Hess, Acting Director for Technology of the Strategic Defense Initiative Organization here in Washington, Dr. Robert Rosen, Deputy Associate Administrator for the Office of Aeronautics and Space Technology from NASA here in Washington. He is accompanied by Dr. Dudley McConnell.

Gentlemen, please proceed. Your full statements will be put in the record. And let us begin with Mr. Bitz.

STATEMENT OF DENNIS A. BITZ, DEPUTY ASSISTANT SECRETARY FOR SPACE AND DEFENSE POWER SYSTEMS, U.S. DEPARTMENT OF ENERGY

Mr. BITZ. Thank you. Good morning. Mr. Chairman, Members of the Committee and staff, I am Dennis Bitz, Deputy Assistant Secretary for Space and Defense Power Systems of the Department of Energy.

Thank you for the invitation to speak before this Committee. I am accompanied on my right this morning at the witness table by Brigadier General Paul Kavanaugh of DOE's Office of Defense Programs.

The charter of the Space and Defense Power Systems program is to meet mission requirements of other Federal agencies, primarily NASA and the Department of Defense, through development, design, fabrication and testing of radioisotopes and nuclear reactor electrical power systems.

The Department of Energy has a long and proud record of providing nuclear power, and safe nuclear power, for U.S. space missions. I personally believe it is in the nation's best interest to continue that effort.

In today's testimony I will briefly describe our past and present space nuclear power programs, and I will stress the importance of safety and the strategies the U.S. is taking, and has taken, to minimize the risks associated with launching and using nuclear power sources in space.

I understand the Committee is also concerned about the potential of the reactor powering the Soviet satellite, Cosmos 1900, to reenter the earth's atmosphere, possibly resulting in radioactive contamination here on earth.

While that subject is addressed in my written testimony, General Kavanaugh is here to address your questions on emergency planning, as Defense Programs is the responsible organization for coordinating this planning for the Department.

Since the primary U.S. users of these power sources, NASA and the Department of Defense are also testifying today, I will defer to them on discussion about the missions that utilize nuclear power sources.

Depending on mission requirements, nuclear power for space applications possesses several advantages over other technologies. It is compact, has low mass and size at higher power levels, has a long life, is insensitive to the orientation and relative position and distance from the sun, and can better survive the natural space environment or an attack.

To cover the full range of power requirements, four different types of devices have been developed, or are under development, through the Department of Energy's program.

The first visual in my written statement illustrates the type of power sources and the range of the electrical output that they deliver. I will briefly touch on each one of these.

Radioisotope thermoelectric generators (RTGs) have served as the principal U.S. nuclear space power system over the past 25 years. An RTG, or what one might call a nuclear battery, is essentially a power conversion system with no moving parts, where the heat from the isotopic fuel source is converted into electricity.

Since 1961 the United States has launched 21 NASA and military space missions having all or a significant portion of their electrical power requirements met by RTGs. The history of RTG-powered missions vividly demonstrates the reliability and safety of these systems.

Eighteen of these missions were fully successful, two launches did not achieve successful orbit, and one mission, Apollo 13, was aborted.

In the three RTG missions in which the primary mission was not achieved, the last occurring in 1970, the RTG safety performance met all design and safety requirements. A photograph of an RTG being used during a lunar mission is included with my written testimony.

Safety has been and continues to be an integral part of RTG operation, particularly in the area of heat source design. DOE has spent substantial amounts of money in a testing and analysis program to confirm RTG capabilities to withstand all types of potential accidents while containing the fuel.

The U.S. has enjoyed an unblemished safety record in its use of nuclear power sources in space. Although there have been some failures that have occurred on launch vehicles or the payloads, in every instance the nuclear safety systems functioned as designed with no discernible impact on public health.

There is a reason for this successful safety record. We take safety very seriously. It has been and will continue to be our number one priority.

Safety encompasses all mission phases, from ground handling to final disposition of the nuclear power source. The safety considerations for various mission phases are illustrated in the third visual with my written statement.

Historically, the safety program on space nuclear reactors and radioisotope power sources has been conducted in two parts, project safety and independent safety. The former is the project's line safety program associated with the design and development of the reactor by the designers and manufacturers.

Independent aerospace safety programs are also established to investigate safety issues over a range of accidents, even unlikely ones, from launch to aborted reentry, with their input continually provided to the particular project.

With regard to the performance of U.S. reactors in space, the SNAP 10A reactor program, which was begun in 1958, culminated with the launch of the reactor into space on April 3rd, 1965.

After 43 days of successful performance, spacecraft instrumentation not directly connected with the reactor operation malfunctioned, causing a sudden shutdown of the reactor. The reactor is in an 800-mile orbit. It will not return to earth for several thousand years.

Before SNAP 10A was qualified for flight, numerous special tests were performed, including reentry flight demonstrations to determine potential reentry impacts. A picture of the SNAP 10A reactor undergoing an electrical checkout is included as a fourth exhibit with my written testimony.

It should be noted that with the SNAP 10A launch, the United States was the first to operate a reactor in space. It was done safely then, and it can be done safely again in the future.

The fundamental safety tenets of the reactor and isotope power programs, remain unchanged to this day. And that is, systems will be designed and tested to assure their safety.

We are also developing a space nuclear reactor called SP–100, for which design and hardware fabrication is now under way for a prototype model to be ground tested in the early 1990s.

And finally, the Multimegawatt Space Reactor program, started earlier this summer with six contractors initiating work on the first phase of conceptual studies.

The SP–100 program is a joint project sponsored by the the Department of Defense, NASA and the Department of Energy. It has been ongoing since the first system conceptual studies were initiated in 1983.

An artist's concept of SP–100 is shown in the last visual with my written testimony. As shown there, the reactor core is at the very front end of the cone-shaped portion, and is only about the size of a five-gallon can.

I will now address the specific actions that we as system developers take to minimize the risks associated with the launching and use of nuclear reactors in space. Safety has been and continues to be of paramount importance in our space nuclear power programs.

For the SP–100 program—now being designed with fabrication, of systems and components ongoing in preparation for ground testing—we are addressing the technical and design bases of potential radiation hazards or the release of radioactive materials on the launch pad, during launch or ascent, during operation in space, after the mission is completed and the reactor is shut down, and finally during any accidental reentry, no matter how unlikely the event may be. We review each item from a safety aspect.

To assure the successful accomplishment of our safety objectives, we have established this comprehensive safety program. We look at it both from the standpoint of safety, quality and reliability in design and fabrication decisions at all levels.

A ground reactor test program is planned to be conducted on the Federal government reservation near Richland, Washington, at the Hanford Westinghouse Company in 1992. The testing program is to confirm the very extensive safety studies before the system and hardware are qualified for routine use as a space reactor power source for spacecraft in the mid-1990s.

There are major differences between the U.S. and Soviet nuclear reactor programs. The Soviets operate in very low orbits, which have orbital lifetimes which are generally less than six months.

To avoid reentry of highly-radioactive materials, the Soviets must boost the spacecraft to a higher orbit immediately after the end of the operation. If the spacecraft malfunctions they may have very little time to correct the problem.

Most long-term operational orbits that the U.S. is now considering for future space missions have lifetimes of hundreds of years to millions of years, not months. We do not intend to allow the operation of a reactor until the spacecraft's planned orbit is achieved, and we know that there is essentially no risk of premature reentry.

Soviet systems are designed to burn up and disperse the reactor core in the earth's atmosphere, if the spacecraft malfunctions and reentry occurs. Potential U.S. safety missions are designed so that once operating, the reactor will not accidentally reenter.

However, as an added safety precaution, the system will be designed to accommodate accidental reentry. The reactor power system will be designed and tested to reenter intact, and to bury itself upon impact in soil or the pavement. This will ensure that the reactor material should be contained within a small area.

The United Nations has also been actively involved in considering the use of nuclear power sources in space. The U.S. delegation has been an active participant in these deliberations.

A special technical working group issued a report in 1981 that remains the definitive technical text. The conclusion of the 1981 technical report is still a succinct statement of the U.N. consensus and of the U.S. position:

"The working group reaffirmed its previous conclusion that nuclear power sources can be used safely in outer space, provided that all necessary safety requirements are met."

Plans have been prepared to respond to a Cosmos 1900 reentry. The Federal Radiological Emergency Response Plan will be a basic plan to be used for responding to the Cosmos 1900 reentry, should it occur in the U.S.

The Federal Emergency Management Agency, FEMA, has coordinated the specific Federal procedures to be used in the eventuality of a Cosmos 1900 return.

Since DOE maintains the technical resources and sophisticated equipment, DOE has been identified as the lead agency for Federal emergency response for radiological monitoring and assessment of such an incident as Cosmos 1900.

If the need arises, DOE will be prepared to handle this radiological response. Contingency plans have been prepared and we stand ready.

In conclusion, I would like to reiterate that the U.S. has safely used nuclear power sources in space since 1961, and has successfully and safely operated a nuclear reactor in space.

In every use of nuclear power sources in space by the United States, all safety systems have functioned exactly as designed. Nuclear power sources were and continue to be an integral part of space exploration.

The U.S. design philosophy has been and remains totally committed to safety in every aspect of space nuclear power development.

Thank you for the opportunity to speak before this Committee.

[The prepared statement of Mr. Bitz follows:]

STATEMENT OF DENNIS A. BITZ
DEPUTY ASSISTANT SECRETARY FOR SPACE AND DEFENSE POWER SYSTEMS
U.S. DEPARTMENT OF ENERGY
BEFORE THE
SENATE COMMITTEE ON ENERGY AND NATURAL RESOURCES

SEPTEMBER 13, 1988

Good morning, Mr. Chairman, and Members of the Committee. I am Dennis Bitz, the Deputy Assistant Secretary for Space and Defense Power Systems at the Department of Energy. I am accompanied at the witness table by Brigadier General Paul Kavanaugh of DOE's Office of Defense Programs. Thank you for your invitation to speak before this Committee.

The charter of the Space and Defense Power Systems program is to meet mission energy requirements of other Federal agencies, primarily the National Aeronautics and Space Administration (NASA) and the Department of Defense, through the development, design, fabrication, and testing of radioisotope and reactor electrical power systems. The Department of Energy has a long and proud record of providing safe nuclear power for U.S. space missions. I personally believe it is in the Nation's best interest to continue that effort.

In today's testimony I will briefly describe our past and present space nuclear power programs. I will stress the importance of safety, and the strategies the U.S. is taking and has taken to minimize the risks associated with launching and using nuclear power sources in space. I understand that the Committee is also concerned about the potential for the reactor powering the Soviet satellite Cosmos 1900 to reenter the earth's atmosphere, possibly resulting in radioactive contamination. While that subject is addressed in this written testimony, General Kavanaugh will address your questions on emergency planning as Defense Programs is the responsible organization for coordinating this planning for the Department.

Depending on mission requirements, nuclear power for space applications possesses several advantages over other technologies in that it is compact; has a low mass and size at higher power levels; can be designed for long life; is insensitive to orientation, relative position and distance from the sun; and can better survive the natural space environment or an attack. The United Nations Working Group on the Use of Nuclear Power Sources in Outer Space has taken a position that, providing appropriate safety precautions are taken, space nuclear power systems are fully acceptable. Since the main U.S. users of these power sources, NASA and the Department of Defense, are also testifying today, I will defer discussion of the missions which would utilize nuclear power sources to them.

To meet the various mission requirements, power levels from one watt to many hundreds of kilowatts are required. Radioisotope power systems are used in the power range of watts to a few kilowatts. Reactor systems are employed at power levels above a few kilowatts.

To cover the full range of these requirements, four different types of devices have been developed or are under development. The first visual accompanying my written statement illustrates the type of power sources and the range of electrical output they deliver.

Radioisotope Thermoelectric Generators (RTGs) have served as the principal operational U.S. nuclear space power system. An RTG is essentially a power conversion system with no moving parts in which a thermoelectric system converts the heat from an isotopic fuel source directly to electricity. Since 1961, the United States has launched twenty-one NASA and military space missions having all or a significant portion of their electrical power requirements met by RTGs. The history of RTG powered missions vividly demonstrates the reliability and safety of RTG systems. Eighteen of these missions were fully successful; two launches did not achieve successful orbit and one mission (Apollo 13) was aborted. In the three RTG missions for which successful orbits were not achieved, the last occurring in 1970, the RTG safety performance met all design/safety requirements. In 1964 SNAP-9A burned up on reentry as intended. At that time the safety strategy was to assure that such launches/failures would result in burnup at high altitudes. The strategy was subsequently revised to require reentry intact. In 1968 the SNAP-19 nuclear heat source was retrieved intact from the Santa Barbara channel after a launch abort. In 1970 the SNAP-27 nuclear heat source was returned intact to the South Pacific Ocean after the Apollo-13 flight abort. A photograph of an RTG being used during a lunar mission is included.

Safety has been and continues to be an integral part of RTG system operation, particularly in the area of heat source design. DOE has a substantial testing and analysis program to confirm RTG capabilities to withstand all types of potential accidents while containing the fuel.

By adding additional equipment to the RTG, electric output may be increased by a factor of three. A Dynamic Isotope Power System (or DIPS) program is now underway to produce up to about 10 kilowatts of electricity, using a turbine energy conversion system.

The U.S. has enjoyed an unblemished safety record in its use of nuclear power sources in space. Although some failures have occurred in launch vehicles or payloads, in every instance the nuclear safety systems functioned as designed, with no impact on public health. There is a reason for this successful safety record. We take safety very seriously; it has been and will continue to be our number one priority. Safety encompasses all mission phases from ground handling to final disposition of the nuclear power source. Safety considerations for the various mission phases are illustrated in the second visual in my written statement.

Historically, the safety program on space nuclear reactors and isotopic power sources has been conducted in two parts - project safety and independent safety. The former is the project's line safety program associated with the design and development of the reactor by the contractor. An independent Aerospace Safety Program was also established to investigate issues such as reactor neutronics at launch and reentry.

With regard to the performance of U.S. reactors in space, the SNAP 10A reactor program began in 1958 with launch of the reactor into space occurring on April 3, 1965. After 43 days of successful performance, spacecraft instrumentation not directly connected with the reactor operation malfunctioned, causing a sudden reactor shutdown. Failure analysis concluded that the most plausible cause was a spurious spacecraft command signal resulting from high voltage failure of the spacecraft's telemetry system. The reactor is in an 800 mile (1287 kilometer) orbit and will not return to earth for several thousand years.

Before the SNAP 10A was qualified for flight, special tests were required, including reentry flight demonstrations to determine the reentry disassembly of the system and the burnup of fuel elements, safety neutronic analyses and tests, trajectory, stability, breakup, aerodynamic heating, thermochemical, thermomechanical, ablation and terminal velocity tests, analyses, and evaluations. A picture of the SNAP 10A reactor undergoing electrical checkout is included.

It should be noted that, with the SNAP 10A launch, the U.S. was the first to operate a reactor in space. It was done safely and can be done again safely in the future.

The fundamental safety tenets of the early reactor and isotope power programs remain unchanged to this day, that systems will be designed and tested to assure their safety.

We are also developing a space nuclear reactor called SP-100, for which design and hardware fabrication is underway for a prototype model to be ground tested in the early 1990's. Finally, the Multimegawatt Space Reactor (or MMW) program earlier this summer signed six contracts for conceptual studies.

The SP-100 program is a joint project sponsored by the Department of Defense, the Department of Energy, and NASA, and has been ongoing since the first system conceptual studies were initiated in 1983. An artist's concept of the SP-100 is shown. The reactor core (the very front-end of the "cone" shaped portion) is only the size of a 5-gallon can; other portions of the device include the radiators, to dissipate excess heat; the boom, through which power cables pass; and the user module (shown as a cylinder, although its exact shape would be mission specific.) Other major components which are not visible are the reactor cooling loops, and the thermoelectric devices which convert the reactor heat directly to electrical energy.

I will now address the specific actions that we as the system developers take to minimize the risks associated with launching and using nuclear reactors in space.

Safety has been and continues to be of paramount importance in our space nuclear power programs. For the SP-100 program--now being designed with fabrication of systems and components ongoing in preparation for ground testing--we are addressing the technical and design issues of potential radiation hazards or release of radioactive materials on the launch pad, during launch or ascent, during operation in space, after the mission is complete and the reactor is shut down, and during accidental reentry, no matter if such an event is highly unlikely. The flow diagram included illustrates these considerations.

To assure the successful accomplishment of our safety objectives, we have established a comprehensive safety program. Safety autonomy is emphasized in our management structure. Our decision process emphasizes and integrates safety, quality, and reliability into design and fabrication decisions at all levels, and we are working to further expand a safety culture built into space nuclear power activities to assure long-term safety commitment.

Our commitment to safety has dictated design changes in the SP-100. Examples of these design changes which were incorporated into the baseline design due to safety considerations include adding a reentry cone to assure intact reentry, increasing the number of control rods from four to seven to assure criticality would not occur at reentry, even on impact with concrete, and the addition of a backup cooling loop which would keep the reactor from overheating in the event primary coolant flow were lost while operating in space. In each case these features were incorporated even though they might be considered as a weight penalty to the design and some future application.

The SP-100 reactor is designed to remain subcritical when subjected to a wide range of accident scenarios, including water immersion and flooding, burial, and launch explosions. The Instrumentation Subsystem is also designed to reliably shut the reactor down in the event of a number of potentially serious off-normal conditions, including: over-temperature, loss-of-coolant, loss of altitude or attitude control, and extended loss of communications. Redundant, autonomous on-board controllers provide protection should communication with the ground be lost temporarily.

A ground reactor test program is planned to be conducted on the Federal Government reservation near Richland, Washington, at the Westinghouse Hanford Company in 1992. A non-nuclear test of the thermoelectric devices and associated systems is planned for 1994. The program would culminate with a flight of an SP-100 space reactor power system in the mid-1990's. This whole series is intended to confirm the very extensive safety studies before the system is qualified for routine use.

There are major differences between the U.S. and Soviet nuclear reactor programs. The Soviets operate in very low orbits which have orbital lifetimes which are generally less than 6 months. To avoid reentry of highly radioactive material, the Soviets must boost the spacecraft to a higher orbit immediately after the end of operation. If the spacecraft malfunctions, they may have very little time to correct the problem. Most long-term, operational orbits that the U.S. is now considering for future space missions have lifetimes of hundreds of years to millions of years, not months. We do not intend to allow operation of the reactor until the spacecraft's planned orbit is achieved, and we know that there is essentially no risk of premature reentry. Soviet systems are designed to burnup and disperse the reactor core in the earth's atmosphere if the spacecraft malfunctions and reentry occurs. Potential U.S. space missions are designed so that once operating, the reactor will not accidentally reenter. However, as an added safety precaution, the system will be designed to accommodate accidental reentry. The reactor power system will be designed and tested to reenter intact and to bury itself upon impact in soil or pavement. This will ensure that the reactor material would be contained within a small area.

The United Nations has also been actively involved in considering the use of nuclear power sources in space. As a result of the reentry of Cosmos 954 over Canada in January 1978, the United Nations considered what should be done regarding the use of nuclear power sources in outer space. The U.S. delegation has been an active participant in these deliberations. A special technical working group issued a report in 1981 that remains the definitive technical text. The conclusion of the 1981 technical report is still a succinct statement of U.N. consensus and of the U.S. position: "The Working Group reaffirmed its previous conclusion that nuclear power sources can be used safely in outer space, provided that all necessary safety requirements are met."

The U.N. is continuing its deliberations on the use of nuclear power sources in outer space. Although no complete set of legal principles has yet been agreed upon, certain scientific and technical criteria for the safe design and use of nuclear power sources have been accepted by the Committee.

Finally, with regard to the Soviet satellite Cosmos 1900, we have learned much from two previous reentries of Soviet reactors, statements by the Soviets to the U.N. regarding Cosmos 1900, and information provided to members of DOE's staff with Soviet space reactor experts at the U.N. in June.

Cosmos 1900 is one of a series of Soviet reactors which have been in use since 1967, with Cosmos 1900 being the thirty-second in the series to be launched. These reactors are thought to carry about 100 pounds of enriched uranium fuel.

These reactors are operated in a very low orbit, approximately 250 km (or 155 miles), with an operational life of only a few months. At the end of operational life, the reactor subassembly is planned to be boosted to a higher orbit, approximately 950 km (or 590 miles), to delay its reentry into the atmosphere and provide time for fission product decay. Two previous reactor subassemblies of the Cosmos series failed to be boosted and have reentered the earth's atmosphere. Cosmos 954, the sixteenth in the series, failed to boost to a higher orbit and reentered the atmosphere in January 1978, with the reactor initially operating and the satellite structure, including the reactor subassembly, intact. Many radioactive components reentered and landed in Northern Canada. After this event, the design was modified to allow the reactor to eject the core from the satellite at the end of operational life. Therefore, if the reactor subassembly did not boost on command, the reactor core would have a better chance to disperse during reentry. In a later system, Cosmos 1402 failed to boost its reactor core; however, the core was successfully separated from the satellite and completely dispersed during reentry, causing no risk to the public.

Soviet space expert and first secretary at the Soviet Embassy in Bonn, Leonid Valevich, on August 19 stated to journalists that there is no radio contact with Cosmos 1900, but that two fail-safe mechanisms exist. He stated that the satellite will continue to gradually decay in orbit until it reaches an altitude of 120 km (75 miles), whereupon the nuclear reactor will be automatically boosted to an 800 km (500 mile) orbit. If this boost system does not function, the reactor core would be automatically released when the satellite's temperature increases due to friction in the upper atmosphere, and it would disperse completely during reentry; this should occur without any significant increase in the natural level of radiation. Reentry would take place in late September or early October. He also stated that a more precise prediction of the time and place of reentry can be made after the automatic separation function.

If the Cosmos 1900 boost system should fail, based on the events that occurred during the reentry of Cosmos 954, it is probable that the reactor system will disassemble during reentry. It is unlikely that debris will impact land, and it is more unlikely that impact will be in a densely populated area. Federal and State agencies, however, must plan for that possibility.

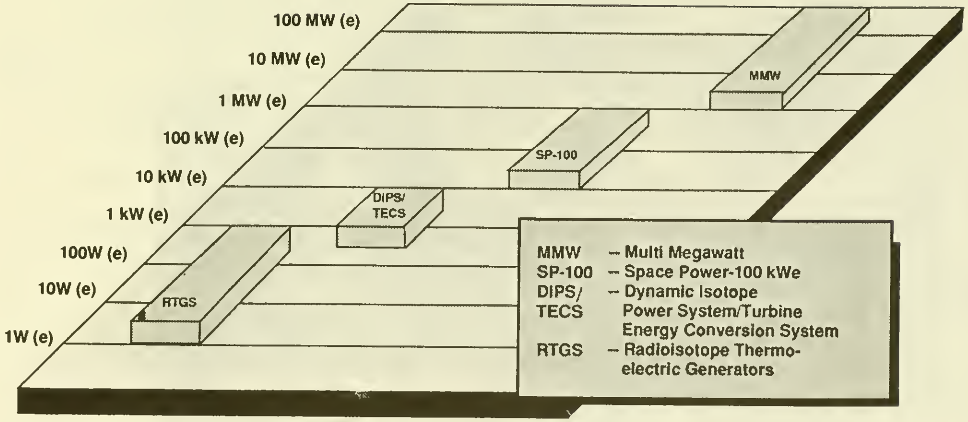
The Federal Radiological Emergency Response Plan will be the basic plan to be used for responding to a Cosmos 1900 reentry in the U.S. The Federal Emergency Management Agency (FEMA) has coordinated specific Federal procedures to be used in the eventuality of a Cosmos 1900 return. The Federal Radiological Emergency Response Plan is a generic response plan for radiological emergencies, published in 1985, which has been fully tested with two operational exercises. FEMA has the Federal government's lead for emergency planning. The plan primarily identifies how Federal support can be provided to State and local Governments who have jurisdiction of the emergency. Since DOE maintains technical resources and sophisticated equipment, DOE has been identified as the lead agency for the Federal emergency response for radiological monitoring and assessment for such an incident as Cosmos 1900. If the need arises, DOE is well prepared to handle this radiological response. Contingency plans have been prepared and we stand ready.

In conclusion, I would like to reiterate that the U.S. has safely used nuclear power sources in space since 1961, and has previously successfully and safely operated a nuclear reactor in space. In every case of the use of a nuclear power source in space by the United States, all safety systems have functioned exactly as designed. Nuclear power sources were, and continue to be, an integral part of space exploration. U.S. design philosophy has been, and remains, totally committed to safety in every aspect of space nuclear power development.

Thank you for this opportunity to speak before this Committee. General Kavanaugh and I will be pleased to answer questions you may have.

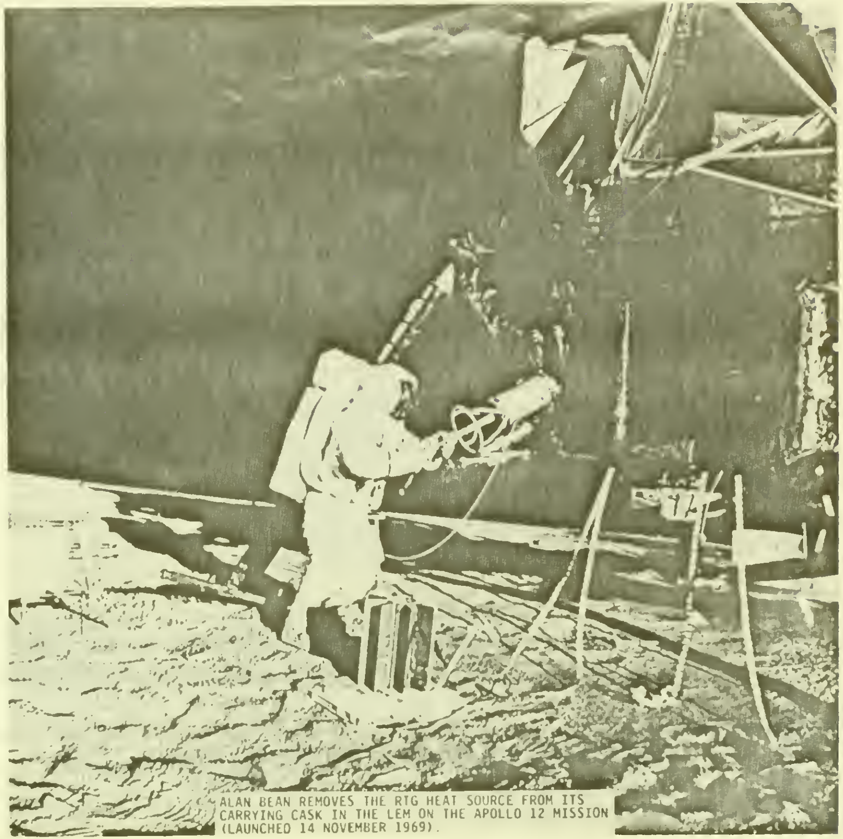
DOE SPACE NUCLEAR PROGRAMS

RANGE OF ELECTRIC POWER OUTPUT COVERED BY SPACE AND DEFENSE POWER SYSTEMS PROGRAM



MMW -- Multi Megawatt
SP-100 -- Space Power-100 kWe
DIPS/ TECS -- Dynamic Isotope Power System/Turbine Energy Conversion System
RTGS -- Radioisotope Thermoelectric Generators

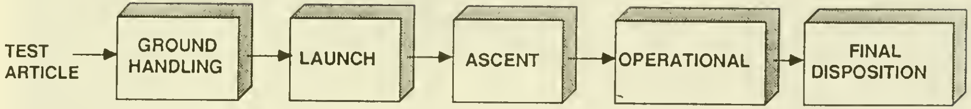
18L02/9-2-88



ALAN BEAN REMOVES THE RTG HEAT SOURCE FROM ITS CARRYING CASK IN THE LEM ON THE APOLLO 12 MISSION (LAUNCHED 14 NOVEMBER 1969).

DOE SPACE NUCLEAR PROGRAMS

SAFETY ENCOMPASSES EVALUATION OF ALL MISSION PHASES



GROUND HANDLING	LAUNCH	ASCENT	OPERATIONAL	FINAL DISPOSITION
⊙ WORKER OVER-EXPOSURE	• EXPLOSION	• EXPLOSION	• REENTRY AND IMPACT FROM ORBIT	• REENTRY AND IMPACT FROM ORBIT
• IMPACT	• FIRE	• FIRE	⊡ LOSS OF COOLING	⊡ LOSS OF COOLING
⊙ LOSS OF AUXILIARY COOLING	⊙ SHRAPNEL	⊙ SHRAPNEL	• RETRIEVAL	• RETRIEVAL
• FIRE	• IMPACT	• IMPACT	⊙ DISPERSION	⊙ DISPERSION
⊙ PUNCTURE	⊙ LOSS OF AUXILIARY COOLING	⊙ LOSS OF AUXILIARY COOLING		
⊙ DISPERSION	⊙ DISPERSION	• RETRIEVAL		
		⊙ DISPERSION		

LEGEND:
⊙ RTG SPECIFIC
⊡ REACTOR SPECIFIC

1BL01/9 2 88

The CHAIRMAN. Thank you. The next witness will be Colonel Culbertson. Colonel Culbertson, I notice your statement is a short one. Nevertheless, we would appreciate it if you would summarize it. But if you wish to read a short statement, that would be fine.

STATEMENT OF COL. HENRY G. CULBERTSON III, USAF, CHIEF, SPACE CONTROL OPERATIONS DIVISION, U.S. SPACE COMMAND

Colonel CULBERTSON. Good morning, Mr. Chairman, and gentlemen.

I am Grady Culbertson from United States Space Command, and I work in the Space Surveillance Center in Cheyenne Mountain where it is our responsibility to track and monitor all man-made objects in orbit around the earth.

The Air Force had asked that we in the Command send a representative to address your question on the anticipated fate of Cosmos 1900. And that is why I am here. I appreciate the opportunity to speak before you.

I have submitted a written statement that you mentioned, Mr. Chairman. And I do have a few charts, if you will allow me, I'd like to show on the screen and just talk through what I have.

What we know, Mr. Chairman, and Committee, what we know about the return of Cosmos 1900 is a combination of what the Soviets have said, they have made numerous statements in open releases, and what it is that we can see from our own space track network.

I will line this chart up here so that you have two columns on the left. On the left you see just brief words on what the Soviet reports have been, and on the right is the way in which we can confirm those.

As you see, the Soviets said that they launched Cosmos 1900 in December of 1987, and as a matter of fact we catalogued the object's first track on the 12th of December, 1987, which was shortly after launch. So that is consistent.

The Soviets did announce that the purpose of the satellite is for scientific research, most especially for oceanological studies. We can accept that as being what they use the satellite for.

Now, last May, what they said is that they lost radio contact with——

The CHAIRMAN. Excuse me. You say scientific research, oceanological studies, like keeping up with our ships?

Colonel CULBERTSON. Well, their words are oceanological studies.

The CHAIRMAN. You accept that?

Colonel CULBERTSON. Yes, sir. We accept that.

The CHAIRMAN. It is the first time I have ever heard that.

Colonel CULBERTSON. They did say that in May they lost radio contact with Cosmos 1900 the previous month in April. As a matter of fact, I am going to show you a chart that shows you how we confirmed that.

Similarly, the next thing is they say that not the orbit but the attitude of the spacecraft, that is its orientation, wherever it is, its orientation has remained stable.

Now, in this particular chart right here, this is more of value for the concept that it represents rather than the precision of it. But what you see is the line across the top at 280 kilometers shows that it was fairly stable from the time it was launched in December of 1987 until about April.

Then you see in April it began to tail off a little bit. Imperceptibly at first, but we noticed it was tailing off. And then by the May announcement on the part of the Soviet Union that they lost radio contact explained that.

Now, they did say that the object, even though they lost radio contact with it, they say that the object was remaining stable. That is, it was moving in a direction of least resistance.

In any event, you see that the slope here, the slope is a fairly stable slope, out through the August timeframe. That slope means that the spacecraft was gradually coming back to earth. And the fact that that slope is so regular indicates that it was in the same, presenting the same drag coefficient as it had all along.

So what we see in our drag coefficients seem to indicate that their statement that it is remaining stable is true. It tails off a little bit there at the end, but that is probably because we are getting low enough into the upper atmosphere that the drag is increasing just because the air is getting thicker.

They also announced that they thought that the return to Earth would be September–October. That is consistent so far as we can compute it at this time. That is consistent with what we think. They announced that it had a nuclear power plant on board, but they also said that they have radiation safety options that I will describe now.

Radiation safety options, there are three. Option 1 is simply when the spacecraft comes to the end of its useful life, a ground command to the spacecraft will be transmitted, the spacecraft will jettison the nuclear power plant from it, and then that nuclear power plant will boost to a higher orbit, an orbit of 800 kilometers. An 800 kilometer circular orbit has a lifetime in excess of 500 years, well in excess of 500 years.

Option 2 is a variation of the first option in that the power plant is jettisoned from the spacecraft and boosted to the same higher orbit. The difference is it is an automatic sequence where the spacecraft either loses attitude control; that is maybe begins to drift out of attitude limits, for example, or when the power, the reactor shuts down, the spacecraft loses power or finally when there is a depressurization in the equipment bay of the spacecraft itself, all of those conditions will set off an automatic sequencing that again will cause the nuclear power plant to jettison and boost to a higher orbit.

Option 3 on the other hand is slightly different. Option 3 is also automatic. It is automatic and is keyed on the heat caused by the friction of reentry. And what that indicates is in the final stages of reentry, just as the spacecraft begins to enter the upper atmosphere and friction builds up and heat builts up, then, at that time, the power plant will be jettisoned forward, will be broken up into bits, and those bits will be consumed by the fire of reentry.

The Soviets said they do not have a commanding system, probably option 1 is not available unless they are able to regain control. Option 2 may still be available. Option 3 is still available. The Soviets seem confident that they will work.

Our responsibility in the command is just what these three bullets say, to track and monitor Cosmos 1900's orbit and predict its reentry time and location. That is not only true for 1900, that is true for anything that is coming back. So, that is not an unusual operation.

The only other thing that we are involved in with Cosmos 1900 is to give as precise a location of any possible debris after the object has already been known to return to Earth.

The CHAIRMAN. Thank you very much, Colonel.

[The prepared statement of Colonel Culbertson follows:]

STATEMENT
ON
THE ANTICIPATED FATE OF COSMOS 1900
BY
COLONEL HENRY G. CULBERTSON III, USAF
CHIEF, SPACE CONTROL OPERATIONS DIVISION,
UNITED STATES SPACE COMMAND
BEFORE THE
SENATE COMMITTEE ON ENERGY & NATURAL RESOURCES
13 SEPT 1988

I. INTRODUCTION

Mr Chairman and distinguished members of the Committee, I am honored to be allowed to appear before you today. My name is Grady Culbertson, and I am from the United States Space Command. I am responsible for the operation of the Space Surveillance Center which tracks and monitors all manmade objects in orbit around the earth. We were asked by the Air Force to address your question as to the anticipated fate of COSMOS 1900.

II. SOVIET STATEMENTS AND PUBLIC RELEASES

What we know about COSMOS 1900 has come from Soviet statements and public releases as well as what we can see with our own Space Surveillance Network (SSN).

The Soviets have said that COSMOS 1900 was launched in December 1987. That is consistent with our initial detection and tracking of the object on 12 December 1987.

The Soviet news agency TASS stated that the purpose of COSMOS 1900 was for scientific research, specifically, oceanological studies. We have no way of confirming or denying that and can only assume it to be the truth.

In May 1988, the Soviets acknowledged that they had been unable to make radio contact with the satellite since the previous month, April. While our observations were in no way conclusive on this point, we had already noticed that the orbit of COSMOS 1900 had begun to steadily decay with no apparent orbital adjustments. Such observations are consistent with their having lost radio contact.

Further, the Soviets stated that the satellite attitude (i.e., the orientation of the satellite body itself) had remained stable; that to say, the satellite was not rolling or tumbling. Had the satellite lost attitude stability, we would have noticed a marked increase in drag, decelerating the satellite faster than expected. This has not been the case, so again our observations are consistent with their statements.

While no precise predictions of when and where the object will reenter the atmosphere can be determined at this point, the Soviet predictions of September or October agree with ours.

The Soviets have publicly stated that COSMOS 1900 incorporates a nuclear power plant. It is this information which separates the reentry of COSMOS 1900 from normal operations and makes it a special case similar to the reentry of COSMOS 954 on 24 January 1978.

Finally, when addressing whether or not the radioactive matter poses a danger to inhabitants of earth, the Soviets claim that certain radiation safety measures built into COSMOS 1900 are "...100%..." certain to prevent danger to Earth.

III. RADIATION SAFETY

The Soviets describe three options which they state confidently will eliminate any danger of the nuclear power plant impacting Earth.

Option one incorporates ground site instructions to the spacecraft telling it to jettison its nuclear power plant and to propel it to a very high orbit where it will remain for hundreds of years. They have already acknowledged having lost radio contact with the satellite so this option is probably not available.

Option two is similar to the first in that it features a separation and boost of the nuclear power plant to a high orbit. It is, however, an automatic function rather than a ground station commanded one. The automatic sequence activates when the satellite either loses attitude stability, loses power, or loses pressure in its equipment compartment. This option may yet occur if any of the activating conditions arise.

Option three is also an automatic activation, but it is keyed by the heat of satellite reentry. The nuclear power plant is jettisoned from the protective spacecraft body, but is not boosted. Rather, the nuclear matter breaks up into small pieces and is consumed by the fire and intense heat of reentry. This option may also yet occur.

IV. USSPACECOM RESPONSIBILITY

Should the radiation safety options fail, some radioactive material may survive reentry and impact the Earth as it did ten years ago when COSMOS 954 left small amounts of radioactive matter in Canada. USSPACECOM's responsibility is to track and monitor the orbital decay of COSMOS 1900. From the track data collected, reentry times and locations can be computed beginning about fifteen days prior to the event. The initial computation is an imprecise estimate of reentry; however, the computations and predictions are refined again and again on an ever increasing frequency. Accuracy of predictions becomes progressively more refined as the time of the reentry approaches. This data is provided to many users including the Department of Energy and the Federal Emergency Management Agency.

Finally, USSPACECOM predicts the location of potential debris after suspected reentry using predictions and computations correlated with Space Surveillance Network sensor or even human observations of the reentry event itself. This information is also made available to the Federal Emergency Management Agency Department of Energy, and others in their attempt to locate and dispose of the materials.

The CHAIRMAN. Next we have Col. George M. Hess, Acting Deputy for Technology of SDIO.

STATEMENT OF COL. GEORGE M. HESS, JR., ACTING DEPUTY FOR TECHNOLOGY, STRATEGIC DEFENSE INITIATIVE ORGANIZATION

Colonel HESS. Thank you, Mr. Chairman, for the opportunity to appear before your committee this morning. I will provide a synopsis of my written testimony, sir.

Satellite systems, both military and civil, continue to become more capable and sophisticated. With the sophistication has come an increasing demand for on-board electrical power for such things as advanced surveillance, data processing, and command and control systems. Satellite designers have historically been limited by the availability of electrical power, and in the future these limitations may represent significant restraints on the capability of future military and civil systems.

To meet the needs for high density, compact, highly survivable power, nuclear power systems may be the answer. The Department of Defense and the SDIO have long appreciated that the deployment of nuclear power sources in space must occur under the most prudent safety procedures and have sought to conduct our own programs in accordance with these strictures.

We recognize that environmental concerns can be created by the deployment of nuclear power sources in earth orbits as witnessed by the experience with Soviet satellites Cosmos 954, 1402 and just recently 1900.

In spite of these experiences and as you pointed out, Mr. Chairman, the Soviets continue to operate systems in orbits and in a manner we in the United States would find unacceptable. As we have learned, complacency is never a good example. Accidents can occur, and if a serious nuclear accident involving a space vehicle occurs anywhere, it becomes a problem for all nations.

I am confident that we will continue to be able to make significant process in space nuclear power safety and that we will be able to satisfy the legitimate concerns of thinking people everywhere.

Before going on and discussing possible safety measures, I would like to first comment on the role nuclear power could play in an SDI system. A broad range of power needs must be satisfied to meet the needs of the SDIO program.

Base load power includes power systems required for continuous operations for long periods of time, perhaps seven to ten years. Near-term missions require on the order of a few kilowatts to approximately 30 kilowatts of electrical energy. With time the demand goes to hundreds of kilowatts and even megawatts of electrical power when electrical propulsion is the load to perform orbit raising and maneuvering.

Burst power systems and burst power requirements are unique to the SDI program. Burst power levels are primarily required for large platforms such as electrically driven lasers, neutral particle beam accelerators or electromagnetic launchers.

To meet both base load and burst power requirements, SDIO is considering all technically feasible means of providing power. Solar energy is and will continue to be the primary base load power source used for most satellites. Major efforts are underway to improve solar power systems and to add significant hardening for survivability to meet SDIO needs.

The SDI goal is to push solar energy feasibility and effectiveness to as high a level as possible. Due to its specific power capabilities; i.e., the ability to deliver large amounts of electrical power at relatively low unit weight, nuclear power becomes the option of choice when high powered hardened systems are needed. Depending somewhat on the spacecraft application, the crossover point between solar and nuclear occurs between 10 and 30 kilowatts.

Advanced solar is an excellent choice at 10 kilowatts. Its mass is around 2,000 kilograms. However at 100 kilowatts, these systems would weigh between 20,000 and 50,000 kilograms, whereas an SP-100 space nuclear power plant would weigh around 4,000 kilograms. This is an advantage we cannot easily ignore.

Nuclear power and unit cost are also projected to be substantially less than solar power costs at high power levels.

SDIO working with DOE has emphasized from the beginning that safety must be a major consideration in the design of any space nuclear power system. I believe we are our own severest critics on the safety issue considering what we have at stake. Features are built into the design to ensure that our safety criteria are met.

Mr. Bitz from the Department of Energy has described some of these features in his testimony, and I will not repeat them here. As a possible long-range option, SDIO has been addressing the question of how to further minimize any lingering risks associated with nuclear power systems in space.

As a result, SDIO is currently evaluating an additional operational safety concept that would provide for permanent disposal of nuclear power sources in space in the unlikely event that other measures to achieve this objective were to fail. This investigation which we have entitled SIREN, standing for space intercept, rescue and expulsion, nuclear, is to develop yet another safety net.

SIREN is aimed at the potential development of means for positive external actions that would prevent reactors from reentering the biosphere should such reentry otherwise appear inevitable. The approach would be a flier to capture a reactor; that is, dock with the orbiting system that is in danger of reentering the biosphere and boosting it to a permanent off-earth disposal site.

If the first attempt to do this were to fail, we reacquire the reactor and continue to do so until success is achieved.

[The prepared statement of Colonel Hess follows:]

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

STATEMENT ON

THE STRATEGIC DEFENSE INITIATIVE

BY

COLONEL GEORGE M. HESS, JR.
DEPUTY FOR TECHNOLOGY
STRATEGIC DEFENSE INITIATIVE ORGANIZATION

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES

UNITED STATES SENATE

100th CONGRESS, SECOND SESSION

SEPTEMBER 13, 1988

Mr. Chairman, thank you for the opportunity to appear before the Committee on Energy and Natural Resources. My name is Colonel George Hess. I am the Deputy for Technology at the Strategic Defense Initiative Organization (SDIO).

Satellites continue to become more complex and sophisticated. Exploring deep space, upgrading air traffic monitoring and arms control monitoring, and fueling powerful systems to defend our country from ballistic missile attack require significantly higher powers than anything used in space thus far. Designers of both civilian and military satellites are limited by the available power sources. Abundant, compact power sources are needed. To meet needs for high power density, compact, highly survivable power, nuclear power may be the answer.

The Department of Defense and SDIO have long appreciated that the deployment of nuclear power sources in space must occur under the most prudent safety procedures, and have sought to conduct our own space program in accordance with these strictures. Lieutenant General Abrahamson, as Chairman of the SP-100 Steering Committee, has directed that safety be built into the SP-100 as a prime requirement. The General continues to reiterate the importance of safety to a successful SP-100 program. We recognize that environmental concerns can be created by the deployment of nuclear power sources in earth orbits as witnessed by the experience with Soviet satellites COSMOS 954, 1402, and 1900. Thus, even though the risks of damage and injury are extremely small, this makes it incumbent on all nations that seek to deploy nuclear power sources in space to abide by a strict safety culture, to cooperate with each in this regard, and to continue to strive for ways to better improve their performance. As we have learned from other examples, complacency is never a good example, accidents can occur, and if a serious nuclear accident involving a space vehicle occurs anywhere it can become the problem for all interested nations. Thus, since the Soviet Union now orbits nuclear reactors in space, and since the United States, France and the United Kingdom have studied future planning options that involve the use of space nuclear reactors, we will work more closely together on safety practices. Safety applies to the deployment of nuclear power sources in space and to continuously look for imaginative ways to increasingly reduce the risks associated with possible accidents.

I am optimistic that we will continue to be able to make significant progress in space nuclear power safety. In my testimony today, I will tell you about one interesting, albeit long-range, option that we are assessing - namely, the so-called SIREN program. This could conceivably supplement the battery of protective measures for civilian and military space missions we already have in hand.

SDIO POWER NEEDS

I would first like to comment on the role nuclear power could play in the SDI program. A broad range of power needs--such as baseload and burst power--must be satisfied to meet the needs of the SDI program. Baseload power includes power systems required for continuous operation for long periods of time, perhaps seven to ten years. The substantial increase in power levels over today's satellites result from several factors. Sensors operate at cryogenic temperature levels and weapons platforms need cryogenic fluids for temperature control; cryogenic refrigeration requires up to 100 kW. Survivable communications devices may require up to 30 kW. High power radar could require 100 kW. Neutral Particle Beams (NPB) and Free Electron Lasers (FEL) require warm up power for radio frequency tubes and other electronic elements that could require up to 100 kW. Near term missions require on the order of a few kilowatts to approximately 30 kW. With time, the demand goes to hundreds of kilowatts and even megawatts when electric propulsion is considered as the load to perform orbit raising and maneuvers.

Burst power is a unique requirement for the SDI program. Burst power levels are primarily required for large weapon platforms that must operate electrically driven lasers, NPB accelerators or electromagnetic launchers. Also, there are extremely large power requirements for active discrimination systems that identify reentry vehicles and decoys. The weapon platform requirements are in the hundreds of megawatts range; discriminators are in the tens of megawatts. The actual length of time required for these bursts of power depends, among other things, on the deployment scenario, the type, number and altitude of the platforms, and the number of operational tests. A few hundred to thousands of second burst time is projected, including provisions for periodic testing of the platform and war game exercises.

POWER TECHNOLOGY ALTERNATIVES

SDIO is considering all technically feasible means of providing power. Solar energy has been, and will continue to be, the primary baseload power source used on many satellites. Major efforts are underway to improve solar power systems and to add significant hardening for survivability to meet SDIO needs. The SDI goal is to push solar energy feasibility to as high a level as possible. The Survivable Power Module (SUPER) program contracts have been awarded to do this. The SUPER goal is a system seven times harder than current technology with a specific power of 2 to 5 W/Kg.

Due to its specific power capabilities, nuclear power becomes the option of choice when high-power hardened systems are needed for survivability. Depending somewhat on the spacecraft mission, the cross over between solar and nuclear power systems occurs between 10 and 30 kW. SUPER is an excellent choice at 10 kW, its mass is around 2000 kg. However at 100 kW, SUPER will weigh between 20,000 and 50,000 kg; the SP-100 space nuclear power plant will weigh about 4000 kg. The mass difference has major implications on the number of launch vehicles needed to meet SDI needs. Also, nuclear power systems do not depend upon orientation for operation and are inherently compact which facilitates maneuvering. Nuclear power unit costs are projected to be substantially less than solar power costs.

To meet SDI burst power requirements four options emerge: chemical turbogenerators, magnetohydrodynamics, electrochemical storage devices and nuclear power. The technology of choice will depend on a number of factors such as the effects of effluent on the platforms, and the specific power, size and volume of the power system. Critical environmental issues exist if effluent from the power system interferes with weapon or sensor performance. Specific power must be improved by a factor of 200 over high power baseload systems to avoid excessive launch costs.

STRATEGIES TO MINIMIZE RISK

SDIO has emphasized from the beginning that safety is a major component in the design of any space nuclear power system. As mentioned earlier, Lieutenant General Abrahamson has repeatedly charged the SP-100 program to address all safety issues. We are our own severest critics on safety. Features are built into the design to ensure that all safety criteria are met. The Department of Energy has described these in their testimony, so I will not repeat the specific features.

As a possible long-range option, SDIO also has been addressing the question of how to minimize any lingering risks to safety and the perception of reactors 'falling out of the sky'. As a result, SDIO is evaluating an additional operational safety concept that would provide for permanent disposal of nuclear power sources in space in the unlikely event that other measures to achieve this objective fail. This investigation, entitled SIREN (Space Intercept, Rescue and Expulsion, Nuclear) is to develop a safety net. SIREN is aimed at the potential development of means for positive, actions that would prevent reactors from reentering the biosphere should such reentry otherwise appear inevitable. The approach would be to acquire or capture a reactor that is in danger of reentering the biosphere and boosting it to a permanent off Earth disposal site; if the first attempt to boost fails, to reacquire the reactor and keep trying until success is achieved. The key here is that with multiple attempts at success, the probability of success is assured to be very high.

Project SIREN is based on the following premises:

- Any given rescue approach might fail. Multiple tries at removing the reactor from low Earth Orbit are mandatory.
- Existing or planned space assets with minimum modifications are to be used.
- The power source or space platform will not be a component of the rescue.
- Earth-based disposal locations will not be considered.

Currently, the program is evaluating various disposal sites from very long life Earth orbits, Lunar orbits, Sun orbits, the Moon, Sun surface, other planets, and escape from the solar system. The planned space infrastructure to support disposal options is being evaluated. For instance, the NASA Orbital Maneuvering Vehicle or a modified version could be used to attach disposal rockets. Both near and far-term strategies are being considered. One of the goals of the current activities is to identify possible modifications to the nuclear power source and other components of the space infrastructure to support permanent disposal. The result of this study will be an implementation and technology development plan. As I have emphasized, SDI space nuclear power systems are being designed to be safe; however, external permanent disposal provides an additional safeguard to the environment.

As I mentioned earlier in my statement, environmental concerns related to the use of nuclear reactors in space is Mankind's concern. Thus, if the concepts in project SIREN prove practicable, such concepts might be shared among nations on an international basis.

SUMMARY

Can SDI get by without the option of nuclear power? Space nuclear power makes it less costly for possible Phase II SDI systems. If nuclear power is not available, an evaluation of alternate architectures will be required. Higher power platforms where SP-100 would be used will need to substitute much heavier solar power system. Other options, such as multiplying the number of platforms, will be needed to meet the survivability requirements. The use of electric propulsion, with twice the performance of chemical rockets, for orbit raising and maneuver will be lost. These modifications imply significant increases in launch costs. Space nuclear power is cost effective, not enabling to SDI. In short, nuclear power will help a strategic defense system to perform its mission better, quicker, and cheaper. The same benefits of nuclear power can be utilized in civilian space missions as well. I want to leave you with the following points about space nuclear power:

- SDI power levels will increase greatly over time.
- Space reactors are a cost-effective approach to meeting SDI needs.
- Technology spin-offs in civil aviation, arms control verification, other DOD missions, and production of materials in space, to name a few are greatly enhanced by space reactors.
- U.S. designs of space reactors meet all established safety criteria.
- Planning is underway to examine the feasibility of an additional safeguard that would help facilitate the permanent disposal of reactors away from the Earth's environment.
- The nuclear power option must be preserved!

Thank you Mr. Chairman. This concludes my statement. I am happy to answer your questions.

The CHAIRMAN. Colonel, if I may interrupt you at that time, each of us has read your statement, and we want to get through the witnesses so that we can get to the questioning because we have so many questions.

Next we have Dr. Robert Rosen, Deputy Associate Administrator for NASA.

Dr. Rosen.

STATEMENT OF DR. ROBERT ROSEN, DEPUTY ASSOCIATE ADMINISTRATOR FOR AERONAUTICS AND SPACE TECHNOLOGY, NASA

Dr. ROSEN. Mr. Chairman and members of the committee, I am Bob Rosen. I am the Deputy Associate Administrator for the Office of Aeronautics and Space Technology, and I have Dr. Dudley McConnell from the Office of Space Science and Applications accompanying me today.

I have a brief prepared statement which summarizes my written text, and I would like to read that now if I may.

I appreciate the opportunity to discuss NASA's requirements for use of nuclear power sources in space and plans for minimizing risks associated with their deployment and operation.

We have studied the application of nuclear reactor power systems for a wide range of potential civil missions ranging from earth orbit to outer space operations and believe that the availability of a safe, high capacity space nuclear reactor is essential for successful execution of many.

High performance reactor power systems offer a viable approach to providing the hundreds of kilowatts of electrical power needed for extended periods of time. In "Leadership and America's Future in Space, a Report to the Administrator," Dr. Sally Ride, addressed future mission options to expand human presence beyond earth orbit and to advance our scientific knowledge of the solar system.

NASA is studying these solar system exploration missions and has identified exploration activities which require power sources with capacities and duty cycles far exceeding today's capabilities. A potential mission in which nuclear power can play a pivotal role involves sustained manned operations on the moon.

For such a base there are just two methods of providing power. The first is a nuclear system and the second is a conventional photovoltaic system consisting of solar collectors and an energy storage system.

To maintain effective base operations during the long lunar night, the photovoltaic system will have to store exceedingly large amounts of energy. This will require a very large storage system and has a significant weight penalty associated with it.

For a base using one megawatt of power, a photovoltaic system will require about three and a half million pounds more launched to low earth orbit than a nuclear system. To provide a better feel for what this means, it is roughly equivalent to the payload of 20 to 25 heavy lift launch vehicles or approximately the payload from seven years' worth of shuttle flights.

Turning now to interplanetary travel, there are two characteristics which I would like to address, the exceedingly long trip times, and the constrained launch windows. We have under development the technology for electric propulsion systems. With a nuclear power source available to supply the necessary energy, these systems would greatly improve the situation for both. Transit times can be significantly reduced.

The time required to go to Neptune, for example, would go from 20 years down to 12 and the launch window constraint nearly eliminated.

Perhaps of equal importance, the increased power available could at planetary encounter be used to enhance the science experiments and increase the data transmission to Earth.

Finally, I would like to address operations in low Earth orbit. Of several possible applications, the most promising is for material processing. At some point in the time potential for commercial activities in the microgravity environment will be realized and when it is, it will take lots of power. A nuclear source may well be required.

At the current time the nuclear capability we will someday need does not exist. NASA is participating with the Department of Energy and the SDIO and SP–100 program to develop and demonstrate in ground tests the key technology.

While not nuclear reactors, NASA has used radioisotope thermal electric generators, RTG's, on a broad range of highly successful science and exploration missions since the 1960's. RTG's have powered the Viking mission to Mars, the Apollo Lunar Science Experiment Packages, and are continuing to provide power to the Voyagers and Pioneers as they head toward the outer reaches of the solar system. They have proved highly reliable and are compact, high power to weight devices that are indispensable to our deep science mission.

Flight operational safety considerations are of paramount importance in the SP–100 program as it is in our RTG programs and the earlier SNAP–10A experimental reactor program. The reactor power system is being designed to meet established and proven national standards and procedures for use of nuclear reactor sources in space.

Safety analyses include assessments of all mission phases from prelaunch preparations through the end of the mission. The system is being designed to be radioactively cold at all times prior to its attainment of operational destination. Only after the planned orbit is achieved and all systems are demonstrated to be operating correctly will the reactor be turned on.

At the end of the reactor's operational life, it will be turned off and placed in an appropriate orbit to allow the radioactive fission products to decay to safe levels. There will be redundant independent safety design features to maintain a subcritical reactor for all credible accident scenarios. In the unlikely event of an Earth's atmospheric reentry, the system is designed to be subcritical and to remain intact upon impact for easy clean-up.

This philosophy is an integral part of the overall SP–100 reactor design and development program and is receiving high program priority. We will continue to examine the most effective ways to meet the safety goals for future operations. The United States' highly effective nuclear systems flight safety review process which will be applied to the SP–100 system has worked very well for over

20 years, and we feel confident that we can assure the American people of minimum risk in launches of future spacecraft with nuclear power sources.

Successful high capacity power technology developments will support future national decisions on solar system exploration missions and will greatly extend our space operational capabilities. The development of space nuclear reactor power enables or enhances missions of national interest both where moderate to high power levels are required or where solar power systems represent an unacceptable or marginal alternative.

This Nation needs to support the development of this promising power technology to assure timely and successful fulfillment of the civil mission operations and objectives.

Thank you, Mr. Chairman, that concludes my statement.

[The prepared statement of Dr. Rosen follows:]

Statement
of
Dr. Robert Rosen
Deputy Associate Administrator for
Aeronautics and Space Technology

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

before the

Committee on Energy and Natural Resources
United States Senate

Mr. Chairman and Members of the Committee:

I appreciate the opportunity to discuss NASA's current and future requirements for use of nuclear power sources in space and plans for minimizing risks associated with the deployment and operation of space nuclear power systems.

I will address the status of our planning for future civil space missions and highlight the nuclear power requirements identified to date from these efforts. NASA's activities for developing a high-capacity power technology base using a high-performance nuclear power source will be presented. Our highly successful, past and current deployments and safe operational uses of nuclear power sources in space will be summed up briefly. The paramount importance of ensuring future operational safety and the SP-100 program plans for providing maximum protection to human health and the environment will be addressed. For the record, the nuclear systems flight safety review process, as developed and implemented by the U.S., has been highly effective and will continue to be applied to nuclear power sources prior to any future U.S. commitment to a nuclear reactor power system deployment and operation.

NASA has used radioisotope thermoelectric generators (RTGs) on a broad range of highly successful science and exploration missions since the 1960's. RTGs have powered the Viking mission to Mars, the Apollo lunar surface experiment packages, and are continuing to provide power to the Voyagers and Pioneers as they head toward the outer reaches of the solar system some 16 years after launch. They are proven high reliability, compact, high power-to-weight devices that are indispensable to our deep space missions.

The President's National Space Policy of 1988 established the long-range civil space goals of the United States and serves to guide our planning for civil space missions well into the next century. NASA has been studying the application of nuclear reactor power systems for a wide range of potential civil missions, ranging from use in low Earth orbit to outer space operations. Assurance of operational safety is a major consideration in these application studies. We believe that development of a safe, high-capacity space nuclear reactor power capability is essential for successful execution of many of these future national space ventures. Reactor power systems offer the only viable approach to providing the hundreds of kilowatts of electrical power or more needed for extended periods of time. I will address considerations for potential future missions in my testimony.

In "Leadership and America's Future in Space, A Report to the Administrator," August 1987, Dr. Sally Ride described an agencywide strategic planning activity that addressed future mission options to expand human presence beyond Earth and to advance our scientific knowledge of the solar system. NASA is currently studying these solar system exploration mission opportunities in greater detail. Studies to date have identified a number of exploration activities which require power sources with capacities and duty cycles far exceeding today's capabilities. NASA's current space technology program and the Pathfinder "Space Nuclear Power (SP-100)" program element, in particular, is structured to provide the technologies needed for these high capacity power systems. The latter activity represents NASA's participation with DOD and DOE in the SP-100 program. The objective of this effort is to develop and validate the technology for space nuclear reactor power systems that can produce tens to hundreds of kilowatts of electrical power and be capable of seven years of operational life at full power. The current phase of SP-100 is to develop and demonstrate key technologies in ground tests of the major subsystems. A flight demonstration of a nuclear reactor power system will be conducted in the next phase of the program.

A potential future mission in which nuclear power can play a pivotal role involves sustained manned operations on lunar or planetary surfaces. The power levels required to provide for human expeditions and their logistics support systems, extended space science research, and in-situ resources development and production can range in the hundreds of kilowatts. If these long duration surface operations occur at sites with extended night periods, the availability of high-capacity nuclear reactor power systems becomes a mission-enabling factor. Although advanced photovoltaic systems could be used for large power generation, very high-capacity energy storage systems would be needed to provide continuous electrical power through the extended night cycle. With even the most advanced energy storage technology, the storage system mass would be extreme. A nuclear power system does not pay the penalty of an extensive energy storage system since it is unaffected by local day/night cycle durations or variations. To be specific, in the power range of interest, the solar power system mass to be delivered to the surface site can be greater than that of a nuclear system by more than a factor of 10. The importance of this mass difference is further clarified when considered in terms of the total operational requirement for mission execution. As an example, consider a lunar base. For every pound of payload delivered to the lunar surface, five pounds of material (payload plus propellants, etc.) must be delivered to low Earth orbit (LEO). For one megawatt of power, the difference in LEO mass is 3,400,000 pounds greater for the advanced solar power system than for the nuclear power system. This is approximately equivalent to the lift capability of 21 additional heavy lift launch vehicles. In addition, other factors such as the possible effects of the local surface environment, e.g., dust, further serve to reduce the performance and life of photovoltaic power generation systems, resulting in additional mass increases.

Two other potential future applications in which nuclear reactor power systems can play a very significant operational role are associated with interplanetary electric propulsion systems. The first involves a propulsion system for large-scale, economic transfer operations such as a LEO to lunar orbit transfer vehicle or a LEO to Mars cargo vehicle. The specific impulse (a measure of efficiency) of nuclear-electric propulsion systems is ten times greater than that of the highest energy chemical propulsion systems currently available. This feature is particularly attractive in unmanned, interplanetary cargo operations when large masses of materials must be transferred in space and trip time is not a critical factor. However, these high-performance electric propulsion systems are feasible only if megawatt levels of power are available; thus, high-capacity nuclear reactor power systems will be required. Once again, the benefit of this application is a substantial reduction in the mass which must be launched into low Earth orbit to conduct the mission.

The second potential future application of importance is the integration of a nuclear-electric propulsion system into a scientific spacecraft to conduct deep space robotic exploratory missions. In this application, a relatively small reactor can power the spacecraft systems as well as the electric propulsion system during transit. Current chemical propulsion systems are limited by propellant weight and often require gravity assist maneuvers to reach the outer planets. This imposes severe launch window constraints. With comparable trip times, an electric propulsion system can provide a direct trajectory which results in much more frequent launch opportunities. Later, during data acquisition phases when propulsion is not required, the relatively high power levels available from the reactor system can be used for enhanced data acquisition. This could enable deeper penetration of dense planetary atmospheres, higher resolution and higher data transmission rates.

Low Earth orbital civil applications of nuclear power can also be of significant interest to the Nation in the 21st century. For example, the space-based radar satellite systems concept for air and ocean traffic control, operating most likely in the Van Allen radiation belts, could be a major boon for needed traffic control operations. Positive air traffic control could be provided to reduce arrival/departure delays, enhance safety, reduce airline fuel costs, and allow system flexibility for unforeseen circumstances.

One of the potentially most promising areas for commercial payoffs in space in future years is in large-scale, space-based materials processing facilities operating in low Earth orbits. The highly advantageous microgravity conditions of space are very conducive to effectual, well controlled production of crystals, glasses, fibers, and biological materials. Other chemical processes such as separation sciences, containerless processing and fluid studies are also receiving considerable attention at this time. However, large amounts of electrical power will be required to take full advantage of these opportunities.

The advantages of high performance, compactness, and the long life potential of the SP-100 space nuclear reactor power system offer considerable application versatility. There is also the potential for power output growth by the use of alternative advanced conversion systems. The capability to provide power for a permanent utility-type, surface base installation as well as for a free-flying spacecraft can be readily effected using the basic SP-100 nuclear systems technology presently under development. Direct use of a reactor's thermal energy for extraterrestrial materials recovery and processing is another area of current interest to the advanced missions planners. Summing up, applications versatility is an essential consideration in the SP-100 nuclear power systems development planning.

As in the RTGs and the earlier SNAP-10A experimental reactor programs, operational safety considerations are of paramount importance in the program. The SP-100 reactor power system is being designed to meet established and proven national standards and procedures for use of nuclear power sources in space. The safety analyses include assessments of all mission phases from pre-launch preparations through the end-of-mission and reactor disposal phase. The system is being designed to be nonoperative at any time prior to its attainment of operational destination. This means that the SP-100 reactor will be radioactively cold; no fission products will have been generated. Only after the planned orbit is achieved and all systems are demonstrated to be operating correctly, will the reactor be turned on. At the end of the reactor's operational life, typically seven years, it can be turned off and placed in an orbit for many hundreds of years to allow the radioactivity of the fission products to decay to safe levels. In addition, there are redundant, independent safety design features to maintain a subcritical reactor configuration for all credible accident scenarios, thereby avoiding any accidental generation of fission products. In the unlikely event of an Earth's atmospheric reentry, the system is designed to be subcritical and to remain intact upon impact for easy clean-up. This philosophy and the safety assessments being performed as related to pre-launch, launch, operations, and end-of-life system disposition conditions are an integral part of the overall SP-100 reactor design and development program and are receiving the highest program priority. We are continuing to examine the most effective ways to meet the safety goals for future operations. The nuclear systems flight safety review process, as developed and implemented to date by the U.S., has been highly effective and will be applied to the SP-100 reactor power system prior to any future U.S approval of an in-space operation of this reactor power system. The continued vigilance demonstrated by past DOE/NASA safety analysis and review processes and the government's Interagency Nuclear Safety Review Panel (INSRP) have worked very well for over 20 years, and we feel confident that we can assure the American people of minimum risk in launches of future spacecraft with nuclear power sources.

Successful high-capacity power technology developments will support future national decisions on implementing solar system exploration missions and will greatly extend our space operational capabilities. The development of space nuclear reactor power enables or enhances missions of national interest both where moderate-to-high power levels are required or where solar power systems represent an unacceptable or marginal alternative. The Nation needs to support the development of this promising power technology to ensure timely and successful fulfillment of future civil mission objectives and operations.

Thank you, Mr. Chairman. That concludes my testimony. I would be happy to answer any questions.

The CHAIRMAN. Thank you very much, Dr. Rosen.

Colonel Culbertson, you say you don't know exactly when or where Cosmos 1900 will come down, sometime in September or October?

Colonel CULBERTSON. Yes, sir.

The CHAIRMAN. Mr. Bitz, Cosmos 954 came down in Canada spreading radioactive waste over a large area. If Cosmos 954 had come down over a populated part of the United States, what would have been the danger presented to people?

Mr. BITZ. Well, sir; looking at it from the standpoint of the analysis that we have done for Cosmos 1900, we believe the exposure to the public, the dose rates, would be much more limited than the early analysis has indicated. Obviously if we had the same circumstances a Cosmos 954——

The CHAIRMAN. The question is if Cosmos 954 had come down in a populated area, what would have been the danger from Cosmos 954.

Mr. BITZ. Sir, I would rather give you a more detailed report. I just do not know the background that much on Cosmos 954.

[The information follows:]

If Cosmos 954 had come down over a populated area, the major risk to people would have been the possibility of being struck by approximately 25–50 pieces of debris, which ranged in weight from grams to several kilograms. The probability of any individual being struck by such debris is very low; the probability of impact from a future reentry on an area which would cause a risk to as many as 500 people is less than one in a million.

A second risk to people if Cosmos 954 had come down over a populated area would be radiation hazard from the debris. Although prolonged exposure to such material would be harmful, it is likely that public notification of the nature of the debris, followed by generally accepted hygiene practices such as bathing and changing contaminated clothing, would serve to limit the number of people who might suffer radiation injury even if a larger population were initially at risk. A recent risk assessment report, which has been provided to the committee, indicates that the expected radiological risk would be statistically less than one-tenth of 1 latent cancer fatality.

The CHAIRMAN. Do you know how much radioactivity there was in Cosmos 954? How many pounds of uranium?

Senator BUMPERS. I can tell you. Fifty kilograms, is that not right?

Mr. BITZ. Sir, I do not have the exact figure. We will get it for you.

The CHAIRMAN. In the same order of magnitude as Cosmos 1900?

Mr. BITZ. Yes.

The CHAIRMAN. All right. Now, the Soviets you have described the safety devices on Soviet satellites which are to kick them into a higher orbit. They can do that manually or it is done automatically if they have a power loss, if the reactor shuts off, or if there is loss of pressure. Did they have those safety devices on Cosmos 954?

Mr. BITZ. We do not believe they did, no.

The CHAIRMAN. All right. Now, what kind of—the Soviets also have a device which is designed to take the core out to eject the core so that the core will burn up in the atmosphere and I think you have stated or Colonel Culbertson has stated that you have high confidence that if that core is ejected that it would burn up in the atmosphere. Is that correct?

Mr. BITZ. That is correct.

The CHAIRMAN. And what gives you that high confidence?

Mr. Bitz. The Soviets had another Cosmos reenter in which the separation did take place. This is the key element. Cosmos 954, to the best of my knowledge, did not have the separation of the reactor from the main spacecraft and so consequently there was radioactive material that reached the ground.

The other Soviet reactor that came in, Cosmos 1402, reentered and burned up in the atmosphere. They did achieve some separation of the reactor core from the main spacecraft.

The Chairman. Now, if it fails to kick into a higher orbit or fails to eject the core automatically and then we would have, would we not, if there is a comparable amount of uranium, we would have a similar situation from that which we had with Cosmos 954.

Mr. Bitz. Certainly the potential is there, yes, sir.

The Chairman. So, really the Soviet system depends upon the credibility of their automatic devices.

Mr. Bitz. That is correct.

The Chairman. What kind of confidence do you have in those automatic devices given the recent manned flight where the automatic devices failed?

Mr. Bitz. Sir, I don't have sufficient detailed information for me to offer a level of confidence to you other than what has been recently reported in the press. We have heard that the systems that were put in place should operate, in contrast with the most recent event. I don't know the connection.

The Chairman. You are not in a position to give an estimate as to how effective those automatic systems are?

Mr. Bitz. That is correct.

The Chairman. Our method of choice picked by the United States in bringing down in the event of an accident, bringing down the core is to encapsulate it so that it will fall and be able actually to go into the earth, is that correct?

Mr. Bitz. That is correct.

The Chairman. Do we feel that is superior to ejection and having it burn up in space?

Mr. Bitz. That is correct.

The Chairman. Why is that?

Mr. Bitz. Because you would bring it in intact and it would all be very localized, rather than have the sort of thing that occurred in Canada. It would be easier to get at and recover.

The Chairman. What is our degree of confidence that—I wanted to say that warhead——

Mr. Bitz. A reentry shield.

The Chairman. The reactor core, what is our degree of confidence that the reactor core would not burn up partially in space or not strew radioactive waste throughout the atmosphere?

Mr. Bitz. It is quite high, Senator. We believe that based on, I think, two major factors. One is that we actually design our radioisotope thermoelectric generators although they are a different technology—so that their general purpose heat source contains the nuclear fuel, which is surrounded by packaging as a kind of heat shield. This device can reenter if it had an aborted orbit, reenter intact and withstand impact on steel plate, as a matter of fact.

The other thing is——

The CHAIRMAN. Have we tested those and brought them back safely with or without an actual radioactive core, but have we brought back the assembly intact?

Mr. BITZ. We have. As a matter of fact, one of the aborted orbits for an RTG occurred very early in the program, way back in the 1960's, and did subsequently go into the Santa Barbara channel and, in fact, the RTG was recovered and the fuel within that RTG was used for a later flight.

The CHAIRMAN. Now, there are a couple of basic differences between the way we put nuclear power systems in orbit and those that the Soviets do.

The principal difference is that we put them in a very high orbit and do not irradiate the fuel until they are in orbit. Is that correct?

Mr. BITZ. That is correct.

The CHAIRMAN. And our orbits are on the order of 800 miles. Is that correct?

Mr. BITZ. That is where we have the SNAP-10A, the first one that we launched. I think we talked in terms of orbits in the 300 or hundreds of years element, which is the distance that could vary in the neighborhood of 400 miles or less.

The CHAIRMAN. I want to make this clear that a fuel element, before it is irradiated, and there is a difference in the danger level before and after irradiation, would you explain that?

Mr. BITZ. Well, the material that is in the reactor core is essentially uranium. It is obviously refined uranium, but it is like that material that appears in nature. It is slightly radioactive, very slightly.

From a hazard standpoint, one could essentially touch the material without any great hazard. And that is the form it is basically in a refined fuel form, and would be in that form all the way through the launch pad until it was placed into orbit.

At that time, when we had it in the acceptable orbit and we wished to start it up, we would proceed to do so. And if we had problems at that point, we have the option to shut it down, which——

The CHAIRMAN. Well, when a core, before it is irradiated, that fell from space, if it was consumed in space rather than staying in its capsule, would that present a hazard to population areas?

Mr. BITZ. No, sir.

The CHAIRMAN. Now, why do the Soviets not use the higher orbit?

Mr. BITZ. I do not know exactly why they do not use the higher orbit. I assume it has something to do with the purpose for which they are using the technology they are using. But I have no specific answer.

The CHAIRMAN. Well, I would suggest that these are military surveillance, that Cosmos 1900 was a military surveillance satellite.

Colonel Culbertson, can you tell us, is it necessary to have the low-earth orbit for military satellites?

Colonel CULBERTSON. As Mr. Bitz said, it depends upon the mission of the satellite, sir, and I assume that the Cosmos 1900, its mission requires that low an altitude.

The CHAIRMAN. Well, would a military surveillance, let us say keeping up with ships, keeping up with where our fleet is, if we were going to do that with theirs, would it require a low orbit or does our technology permit us to use 400 miles or higher?

Colonel CULBERTSON. I would like to defer that question, sir, as long as we are in open session.

The CHAIRMAN. It is not possible for you to say whether that is a requirement?

Colonel CULBERTSON. I could say that the closer look you get at whatever you are looking at the better look it is going to be.

Senator BUMPERS. It does not sound to me like you gave away the store with that answer.

The CHAIRMAN. All right. Col. Hess, you speak in your statement about weapons platforms that would require hundreds of megawatts and discrimination which would require tens of megawatts.

Colonel HESS. Yes, sir.

The CHAIRMAN. Is there any known solar device that can generate that kind of power?

Colonel HESS. Sir, it would depend on what mode of operation you are in that platform.

For housekeeping power, as we tend to call it, for day to day operations, keep the cryogens cool and maintain the computers and the data links, it is conceivable that you could have a solar system of large area——

The CHAIRMAN. That was not my question. My question was that for a weapons platform requiring hundreds of megawatts, or discrimination requiring tens of megawatts, do we have any known solar system?

Colonel HESS. No solar system, sir. But we are investigating chemical non-nuclear techniques for generating burst modes of multi-megawatts of power.

The CHAIRMAN. General Abrahamson was quoted in the Albuquerque Journal of Tuesday, January 12th, 1988. He spoke at the same New Mexico symposium that I spoke at.

And he said that without reactors in orbit "that is going to be a long, long light cord that goes down to the surface of the earth." And I think what he was saying was sort of reinforcing what your statement is, that really nuclear power would be required when you are talking in megawatts.

I mean, it is possible to have a burst mode, but you cannot just have a burst mode, and you probably cannot generate hundreds of megawatts even from a burst mode of a chemical laser.

Colonel HESS. Sir, it is possible to generate burst mode power using non-nuclear techniques.

The bottom line is that nuclear, large nuclear space-based platforms, would probably make SDIO systems more effective and cheaper. However, there are alternative techniques that we could investigate. And in that respect, nuclear power would be the system of choice but is certainly not enabling.

The CHAIRMAN. It is what?

Colonel HESS. It is certainly not enabling. In other words, you have to have it.

The CHAIRMAN. You think you could get along without nuclear power?

Colonel HESS. We would prefer not to have to consider that option. But we could structure options of choice, other systems if necessary, which would be less effective, more costly and heavier.

The CHAIRMAN. Well, you talk about—I mean, I have looked at the figures you have there between this solar system and the SP-100, and you are talking about a difference of 12 times in weight.

Colonel HESS. Yes, sir.

The CHAIRMAN. And the difference in not just mass but the solar would be a huge array out there designed to catch a huge amount of the sunshine, would it not?

Colonel HESS. You are correct, sir.

The CHAIRMAN. And survivability would almost be out of the question, if it were solar. Would it not?

Colonel HESS. We are investigating techniques, as I indicated in the testimony, to push the hardness of solar systems to their theoretical limits.

There is obviously a point in time at which you can only achieve certain levels of hardness with large solar arrays. Survivability is a concern. Moving quickly large masses or large acres or large areas of solar arrays is a legitimate concern.

However, we believe that we could structure options, as I indicated, less cost-effective, heavier, that we could provide if we were forced to.

The CHAIRMAN. Colonel Hess, you have got a difficult problem here in terms of stating the position, because my belief is that SDI certainly for discrimination requiring tens of megawatts and certain weapons platforms, if they are based upon beams, are going to require nuclear power.

I think it is possible, properly structured, to have those reasonably safe. But there is a lot of opposition to that, nuclear power in space. But if you tell this Committee that you do not need nuclear power, I am telling you, it is going to be hard to get SP-100 and the follow-ons funded up here because if there is an option of choice other than that, the Congress is going to go for it.

I would submit to you it is very clear that you have got to have nuclear power in space for all of these platforms that you could not afford, that solar is out of the question. I mean that is out of the question.

You can harden it to its theoretical limits, and you have got this big huge array up there which could be shot down with the most rudimentary space weapon, whereas you can harden a nuclear power system. Now, am I misstating that?

Colonel HESS. No, sir. We need the option to pursue nuclear space power systems.

They will be, for certain applications, the system of choice. They will be more cost-effective, more survivable, and clearly more affordable.

The CHAIRMAN. And anything else is really out of the question.

Colonel HESS. I believe in the inventiveness of the American engineer, sir, that if we were restricted to have no nuclear power that we would address other options.

Senator WALLOP. Mr. Chairman, if you would allow me, the question does not quite go to the heart of the choices.

There is significant chemical lasing capability. But you have different kinds of things. And clearly, NASA is not going to be able to exist without nuclear power and interplanetary kinds of missions that they are talking about, or the space station kinds of missions.

There are lasing options that do not require nuclear power, but then you have other kinds of criteria and requirements that go into that. So Colonel Hess is in an awkward situation not being able to talk very specifically about capabilities.

But the early on SDI capability which I was pushing a long time was a chemical lasing. It would have great capabilities in that. There is more flexibility, I think. It is rather difficult thing for him to talk about in open session.

Colonel Hess. That is correct, Senator. And we have—the initial systems that have been investigated do not have nuclear as an option, and there are certainly initial phase two capabilities, represented by chemical lasers, that will not require nuclear power.

The Chairman. Well, I am familiar with the chemical lasers, and I know that of course they had big problems. You have to push a lot of gas through the device, and while not messing up the view of your sensors while they are doing that. I know you have not solved that problem yet.

Senator Wallop. Space is the ideal environment for that, a perfect vacuum makes mixing of gases rather more easy. But Mr. Chairman, I have to leave.

But I would like to make one observation. And one is that I would hope that neither this Committee, the Congress or the American people would want to constrain American nuclear technology on the basis of the incompetence of Soviet nuclear technology.

If you take a look around at what they have done with submarines, take a look around at what they have done in space and take a look around at what they have done on the earth, it is not anything like the same kind of technology, the same kind of capability or the same kind of concern for safety that exists in American programs right throughout these things.

Our nuclear ships have been safe, our nuclear submarines have been safe, our nuclear space programs have been safe. You get a lot of emotion attached to a nuclear hearing, but it is——

The Chairman. Well, actually I was trying to make that point.

Senator Wallop. I know you were, and that is why I was suggesting that this Committee follow the track that you had been trying to lead us on here, and that we not fall prey to a rather easier political spectrum.

But, you know, let the Soviet system stand on their own and ours stand on our own. And I appreciate what you are trying to get done.

The Chairman. Of course, the one problem, and I think that is true. I think you can put nuclear power systems in space at a higher orbit where it will take thousands of years, and that is a mathematical thing, that it will take thousands of years so that their radioactivity would have decayed, if they ever should fall from orbit, fall back to the earth. But I think it is entirely possible.

But my question is, suppose we deployed SDI, and suppose the Soviets had the same technology, I mean also had an SDI technology, do you suppose they would deploy theirs as well?

Colonel HESS. Sir, it would be difficult for me to speculate as to what Soviet reaction would be to a potential SDI deployment.

The CHAIRMAN. Well, I would suggest to you that it is sort of like Colonel Culbertson's answer, the answer is yes.

Senator WALLOP. Mr. Chairman, first of all you have to look at what the capability is. And second of all, I do not think that it is appropriate for us, we have made that mistake so many times in the past, of trying to mirror image.

Their capability and their research may have well taken them off into areas that are completely different from those that we have.

The CHAIRMAN. I understand. But I think it is legitimate to make the point that while we can do it safely the Soviets do not do it safely.

And there are dangers in getting into an SDI race where they have to do the best they can, and you said there is no danger of a Chernobyl in space. Not of us putting a Chernobyl in space, but there are dangers of the Soviets putting hundreds of Chernobyls in space, if we get in a race on SDI. And I think I have spoken long enough, if you would like——

Senator WALLOP. I would just the observation that I have never heard us as a nation start to talk about the military capability we have based on the incompetence of the capability that they might respond with.

Surely there is more, there is a greater more sophisticated judgment than that. Their response is frankly dangerous if it is competent or incompetent. But the whole problem that we have is their response is always there.

It does not matter whether it is in this field, the field of missilery, the field of conventional weapons, the field of bombers or anything else. They are a dangerous force in the world.

And I think that if we have the means of controlling some of that danger, we ought not to walk away from it on the basis that their response might be incompetent.

The CHAIRMAN. It might be dangerous. That is the problem. Senator Bumpers?

Senator BUMPERS. Mr. Chairman, just an opening observation, before Senator Wallop leaves, and that is, if the Soviet Union's technology, flawed technology, only threatened the Soviet Union, then the point would be well-taken.

Unhappily, if their technology is so inferior to ours, as it obviously seems to be, it is not just the Soviet Union that is going to suffer. Canada has already found that out.

Senator WALLOP. But would you allow me one response? Do you think the collapse of the Soviet satellite is anything like as dangerous as the arrival of a Soviet missile?

Senator BUMPERS. That is a non-sequitur to me. I do not understand that.

Senator WALLOP. Well, if you can shoot down a Soviet missile surely the world is a whole lot safer than if their response happens to disintegrate in orbit.

Senator BUMPERS. That would take about three hours of debate here to get into that.

The CHAIRMAN. What percent of the Soviet missiles can you get? By my calculation, if we deployed this $150 billion program, we would still have about 20,000 warheads left, a little over 20,000.

Senator BUMPERS. Enough to ruin your whole afternoon. Mr. Chairman, one other point I might say is, even if the Soviets, if we deployed SDI and the Soviets had a mirror technology, it is not certain that they would deploy it.

I have always maintained and I still maintain that the Soviet Union would be able to defeat SDI for somewhere between half to 10 percent of the cost of SDI. Now, that is another debate.

But that is something I happen to believe based on what I know right now. And so I do not think they necessarily would unless they did it for political purposes to convince their people that they, too, had an SDI.

But I think from an economic standpoint and a military standpoint, and not a political standpoint, they might choose not to deploy it, because they could save truckloads of money.

I wanted to ask Dr. Rosen, I have heard, and I would like for you to verify this, or deny it, that so far as anything in the foreseeable future from NASA, they do not necessarily see nuclear power systems as being required. Is that a true statement?

Dr. ROSEN. Of approved missions, Senator, that is true. Of the things that we have on our books now, we do not have any requirement today for a nuclear reactor power system. But our researchers, our scientists are very pragmatic, and they are not about to go and design a mission requiring a nuclear power source until a nuclear power source is available.

And so it is a chicken and egg kind of a thing. We are not going to put something on the books that requires a nuclear power source until something like the SP–100 comes along and has been proven so that the people who are devoting major scientific endeavors know that there is a real chance to actually achieve that mission.

Senator BUMPERS. Let me change the course of this, Col. Hess, if I could, or Mr. Bitz, either one, and ask this question.

The Soviet RORSATs have, as my understanding, about a 50-kilogram power system. That is 50 kilograms of enriched uranium in their core. And it is my understanding that our SP–100 would have between 190 and 200 kilograms, a kilogram being 2.2 pounds.

But let us just take the Soviet—well, let us take the SP–100. If it has 200 kilograms of enriched uranium, number one, is that weapons grade material?

Colonel HESS. Yes, sir.

Senator BUMPERS. Number two, that is 220 pounds of enriched uranium. And you say it is our intention to always keep that core reactor contained so that it comes down together. Correct?

Colonel HESS. Yes, sir.

Senator BUMPERS. Now, an important fraction of the land mass of the world is in the Middle East, a very volatile area where about 95 percent of the people do not happen to agree with us.

Now, are you prepared to tell the Committee that if, despite all of your safety precautions, this nice payload of 220 pounds of enriched uranium happens to come down in Libya, you are telling me that Kaddhafi, through a fairly simple process, could not process that material and take the cesium and a little waste out of it?

And it is my understanding it takes 10 pounds to make a nuclear device. So you have the potential there for about 22 nuclear weapons. Are you telling me that Kaddhafi could not recruit the people who could do that fairly miniscule, not highly-technical process of separating a little waste out of that and making weapons?

Colonel HESS. Sir, you have strung an awful lot of ifs together to get to this scenario.

Senator BUMPERS. Well, just start through them as you will. Just give me a categorical no answer, that it could not be done.

Mr. BITZ. Senator, if I might respond to that. It would be extremely difficult for him to do it in a relatively short time, because the fuel form you are talking about, yes you are correct, it is highly-enriched uranium, but it is in the uranium nitride form, which means that it would require some sophisticated chemical processing. It is not impossible even for the Libyans to do that, but it would take them some time.

And we would also know where that device came down in rather short order, and be able to identify its location.

The CHAIRMAN. What percent of enrichment is that?

Mr. BITZ. Ninety-seven percent. But it is not in an easy form to convert directly into weapons material without spending an appreciable amount of time processing it.

Senator BUMPERS. That is pretty highly enriched.

Mr. BITZ. That is correct. But it is not in an easy form for it to be turned into weapons-grade——

Senator BUMPERS. Why not? Tell us, a couple of laymen sitting here, why it cannot be done?

Mr. BITZ. Because it is in the uranium nitride form. It means that you would have to chemically separate out the nitride form in order to have a material that could be utilized for a nuclear device.

Senator BUMPERS. How complicated is that?

Mr. BITZ. It is a fairly complicated process. It is not impossible for others to do that. I am not sure whether in fact——

Senator BUMPERS. I think you are going to be contradicted by other witnesses who appear after you, Mr. Bitz. I may be wrong. I think some witnesses are going to testify that it is not complicated at all.

Mr. BITZ. Well, I guess that would be their opinion, Senator. I feel from a technical perspective that it is more complicated than that.

It is not an unknown technology. I would certainly concede that. But the process and the time that it would take to do that, I think, if we had such circumstances that it came down in Libya, then it would have to be handled perhaps through other means.

But there is a technical circumstance which requires that they do spend some time and effort and have the capability to do that.

Senator BUMPERS. Col. Culbertson, can you tell us with any degree of assurance within 30 days of when the Cosmos 1900 is going to come down?

Colonel CULBERTSON. From 30 days out I could not tell you with any degree of assurance as to when it would come down, sir.

As the time of its reentry approaches, we will get more and more accurate. But we do not have any real degree of accuracy.

Senator BUMPERS. And you do not know when you will be able to predict?

Colonel CULBERTSON. Yes, sir. When—we run a program every day, as a matter of fact, in the Space Surveillance Center, which looks at every object that is in orbit right now, some 7,200 objects.

And every day we come up with, is this object going to come down in the next 30 days? And if the answer is no, we go on to the next point. If the answer is yes, it is going to come back in, then we begin a process that will allow us to do our initial run to predict when it is 15 days away. And then we do another at 10 days, 6 days, 4 days, 2 days, and so forth.

Senator BUMPERS. At what point will you be able to tell the American people where it is going to come down?

Colonel CULBERTSON. At about the two-day point.

Senator BUMPERS. So if it is Manhattan, Manhattan can take cover, huh?

Colonel CULBERTSON. No, sir. Not Manhattan. It will be a lot larger footprint than New York. It may be in the Pacific Ocean or on orbit so-and-so will be at the two-day point.

That continues on through down to, in effect, hourly runs. And it is then that we will be able to say, here is the footprint that it looks like.

Senator BUMPERS. What happens if this nuclear load comes down in a heavily-populated area?

Colonel CULBERTSON. What happens as far as I am concerned, sir, is that we predict where it is coming down, we locate where the most likely pattern was, and we provide that information.

Senator BUMPERS. I understand. But just assume for purposes of argument that you miss, there is no evacuation, and that it comes down in a heavily-populated area. What happens to those people?

General KAVANAUGH. I would like to respond to that. I am Brigadier General Paul Kavanaugh, Deputy Assistant Secretary for Military Applications.

What would happen on this, if it came down, we would assume two cases, impact in the continental United States and impact outside of the continental United States. We would address an impact in the continental United States immediately.

What would happen is if it came down in that area, FEMA would be the overall Federal coordinator. And what they would do is they task the Department of Energy to——

Senator BUMPERS. I am sorry. I did not understand that, General. What would they do?

General KAVANAUGH. FEMA would——

Senator BUMPERS. I understand FEMA would have responsibility.

General KAVANAUGH. They would task the Department of Energy to evaluate the situation. It is our job to ascertain where the contamination is, and to determine what effect it would have on the population in that area.

We would provide technical backup to the State and local authorities.

Senator BUMPERS. General, that is really not quite my question. I am just asking, what happens to these people? I understand all kinds of emergency equipment would be activated and procedures would be activated.

But I am just saying, what happens to the people whose head it falls on?

General KAVANAUGH. If it landed in somebody's house, is that what you are saying? I am having a hard time getting your question.

Senator BUMPERS. I am just saying, if any of this nuclear, any of this uranium falls on the people in this room, what is going to happen to them?

General KAVANAUGH. If it fell on the people in this room, what would happen to them is we would have to make a determination about the severity of the dosage that they received. It could be miniscule or serious.

These people would have to go through cleansing techniques in order to get the particles off of their bodies. Naturally, you would not want to ingest it.

Senator BUMPERS. It is fair to say that it would not be particularly good for their health, would it?

General KAVANAUGH. No, it would not. Ordinarily it comes down in chunks or smaller pieces, and we are able to ascertain where it is.

If, for example, most of the material hypothetically impacted within a city block we would be able to ascertain that, and we would have the people withdraw from the area. Then they would be checked.

The areas that would be highly-contaminated would be decontaminated.

Senator BUMPERS. Mr. Bitz, have we ever discussed the possibility of simply discontinuing putting nuclear power plants in space with the Soviets?

Mr. BITZ. Not to my knowledge, sir.

The CHAIRMAN. If you will yield at that point, Senator Bumpers, I invited Academician Sagdeev, who is Director of the Institute of Space Research of the USSR Academy of Sciences to make a presentation for these hearings.

And summing up what he says, he talks about the dangers of nuclear reactors in space. He says he thinks there is really not a safe orbit, that they do have some dangers.

And he says, "taking all these factors into account, we propose a ban on nuclear power of any sort in earth orbit and a 15-year moratorium on reactors for other space uses. This would not preclude the use of small isotope sources for deep space missions.

"Working discussions on intergovernment level would elaborate the details of such an agreement. For example, foreseeing the possibility of international cooperative deep space missions where nuclear power might play a role sometime in the future."

This statement will be part of the record.

[The statement referred to follows:]

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Dear Senator Johnston,

At your request please find enclosed my statement for the hearings on Cosmos 1900 and the future of nuclear space power.

I want to express my deep appreciation for your invitation to participate in the hearings. Regretfully due to prior commitments I am unable to do that in person. But the issue is so important that I dare to send you my personal statement on the problem.

R Sagdeev

With best regards.
Academician Roald Sagdeev.

STATEMENT OF ACADEMICIAN ROALD SAGDEEV
CHAIRMAN OF THE COMMITTEE OF SOVIET SCIENTISTS FOR PEACE AGAINST THE NUCLEAR THREAT, DIRECTOR OF SPACE RESEARCH INSTITUTE OF THE USSR ACADEMY OF SCIENCES

Mr. Chairman and members of the Committee,

I appreciate your invitation to testify in person on a problem of such importance as the future of nuclear power in space. I regret that according to prior commitments I have to participate in a conference in Geneva at the same time. It is my pleasure, however, to submit this written statement to your hearings on this matter.

In May of this year two organizations, the Federation of American Scientists (FAS) and the Committee of Soviet Scientists for Peace Against Nuclear Threat (CSS),made a joint proposal to ban nuclear power in Earth orbit. The development of technical possibilities for human civilization increases enormously the risk for humankind. Two disasters - Chernobyl and Challenger - forced us to reexamine the use of nuclear power in space.

At present, this direction of scientific and technical activity is at an early stage of development.Up until now, both Soviet and American space programs involved only launches with comparatively moderate amounts of dangerous radioactive materials. This makes it even more important to look realistically at the experience we are having now with radioactive contamination of the environment when accidents take place. The long-term consequences under worst case conditions of an accident involving the large space nuclear reactors contemplated for the future can be comparable to the long -term consequences of Chernobyl. The same can be said of the long-term consequences of accidents involving the isotope power sources containing considerable amounts of Plutonium-238 (for example, the Dynamic Isotope Power System, where the amount of Plutonium would be tens of kilograms).

The concept of a "nuclear safe orbit" where the reactors can exist without the danger of falling down practically forever is still dubious. Nobody can exclude the possibility of technical error, criticality accident, or collision with meteors, which can lead to reactor exploding or disintegrating and then some part of it falling to Earth. A collision with space debris, the amount of which is growing rapidly could also result in such an accident.

In the Space Research Institute of the USSR Academy of Sciences we performed a detailed analysis of possible future scientific missions in near and deep space for the foreseeable future. We were unable to find projects at least for the next 15 years which could not be carried out without the use of nuclear power. Although further study is needed, it now appears that even the manned mission to Mars can technically be realized effectively using the non-nuclear sources of energy.

As I stated at the press conference on May 13 of this year at the National Press Club in Washington, the New Thinking (Perestroika) means getting rid of old garbage. I would include in that category current and planned uses of space-based nuclear power for military purposes. Furthermore I am quite sure that the existence in space of a considerable number even of civilian nuclear sources will always produce a temptation for some people to revive ideas of space militarization, contributing a destabilizing factor to the relations between our two countries.

I consider to be of great importance one more aspect of this problem. This is in connection with the Outer Space Treaty, which prohibits nuclear weapons in space. Space reactors could provide potential violators the opportunity to conceal nuclear warheads in space.

Taking all these factors into account, we propose a ban on nuclear power of any sort in Earth orbit and a fifteen year moratorium on reactors for other space uses. This would not preclude the use of small isotope sources for deep space missions. Working discussions on the intergovernmental level would elaborate the details of such an agreement, for example foreseeing the possibility of international cooperative deep space missions where nuclear power might play a role sometime in the next century.

I have had the opportunity to explain the position of the CSS on the issue of the future use of nuclear power in space to high officials of the Ministry of Foreign Affairs of the USSR. Please permit me now to appeal as well to the members of the United States Senate Committee on Energy and Natural Resources to support our joint proposals on the issue of nuclear power in space.

Thank you for this rare opportunity.

R Sagdeev

ROALD ZINNUROVICH SAGDEEV

Brief Biography

SINCE 1973 ACADEMICIAN ROALD SAGDEEV HAS BEEN DIRECTOR OF THE INSTITUTE OF SPACE RESEARCH OF THE USSR ACADEMY OF SCIENCES. HE IS ALSO A DEPUTY OF THE USSR SUPREME SOVIET AND SINCE 1968 AN ACTIVE MEMBER OF THE ACADEMY OF SCIENCES.

DOCTOR SAGDEEV WAS EDUCATED IN PHYSICS AT MOSCOW UNIVERSITY. BETWEEN 1956 AND 1961 HE WAS A RESEARCHER AT THE KURCHATOV INSTITUTE OF NUCLEAR ENERGY IN MOSCOW. BETWEEN 1961 AND 1970 HE WAS AT THE INSTITUTE OF NUCLEAR PHYSICS LOCATED IN NOVOSIBIRSK, SIBERIA. THERE HE WAS DEPARTMENT HEAD. IN 1964 HE WAS ELECTED CORRESPONDING MEMBER AND IN 1968 A FULL MEMBER OF THE ACADEMY. BETWEEN 1970-1973 HE WAS A SENIOR RESEARCHER AT THE INSTITUTE OF HIGH TEMPERATURES.

IN 1984 DOCTOR SAGDEEV WAS AWARDED THE LENIN PRIZE. HE HAS ALSO BEEN DECLARED A HERO OF SOCIALIST LABOUR.

ROALD ZINNUROVICH SAGDEEV WAS BORN ON DECEMBER 26, 1932 IN KAZAN, TATARS AUTONOMOUS REPUBLIC. HE IS MARRIED AND HAS TWO CHILDREN.

F.A.S.

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U.S.-SOVIET SCIENTIFIC COLLABORATION CONCLUDES THAT A BAN ON NUCLEAR POWER IN EARTH ORBIT IS FEASIBLE AND DESIRABLE FROM BOTH A MILITARY AND ENVIRONMENTAL POINT OF VIEW

A JOINT PROPOSAL TO BAN NUCLEAR POWER IN EARTH ORBIT

The proposal which we put forward on behalf of our two organizations (after two joint workshops) to ban nuclear power in earth orbit grows out of our efforts to prevent both the radioactive contamination of the earth's surface and the extension of the arms race into space. In particular, this agreement would prevent the use of reactors in earth orbit by either side for any purpose — whether offensive or defensive, including the use of reactors to power surveillance satellites.

The use of nuclear power in space is still at an early stage but already there have been accidents which have caused worldwide concern.

An agreement to ban nuclear reactors from orbit would be a major barrier to any future arms race in space since nuclear reactors are compact sources of large quantities of power necessary for many military purposes. Meanwhile, as far as civilian activities are concerned, solar energy collectors and fuel cells will be a more convenient and safer source of energy in earth orbit for the forseeable future. Energy sources powered by quantities of radioisotopes below an agreed safe threshold could also be permitted for these purposes.

The ban on reactors in orbit would not prevent the use of nuclear power for deep space scientific or exploratory missions with associated very limited tests under agreed safeguards of such deep-space reactors in earth orbit.

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Verification of a ban on nuclear power in orbit would be relatively straight forward because an operating (or even recently operating) nuclear power source would emit large amounts of detectable infrared, gamma and neutron radiation.

We therefore call for an international agreement to ban nuclear power in orbit and our two organizations plan to continue to work on the technical aspects of this ban in the context of our 5-year Joint Verification Project.

Roald Sagdeev, Chairman
Committee of Soviet Scientists
Against the Nuclear Threat
Scientists

Frank von Hippel, Chairman
of the research arm of the
Federation of American

The Committee of Soviet Scientists Against the Nuclear Threat, established in 1983, is a non-governmental group of senior Soviet scientists formed for the purpose of scientific and technical analysis of the feasibility of disarmament agreements. Academician Roald Sagdeev, its current Chairman, is Director of the Space Research Institute of the Soviet Academy of Sciences.

The Federation of American Scientists, formed in 1945, is the oldest organization in the world devoted to nuclear disarmament, having been founded by some of the original Manhattan Project scientists for that purpose. It is sponsored by 45 Nobel Prize winners. Its project on "cooperative verification" is directed by Princeton Professor, Frank von Hippel, who serves also as Chairman of the research arm of the Federation of American Scientists (the FAS Fund).

Senator BUMPERS. That is good. That at least answers the question from their standpoint.

Why would it not be good to enter into an agreement with the Soviet Union, Mr. Bitz, to say that both parties just initially will not activate the power system below 800 kilometers?

Mr. BITZ. Well, sir, there may be others on the panel who will discuss this from the user standpoint.

From our standpoint, that is developing the technology, it may be worth it to have discussions. It is not for me to decide. But I think it would require some rather lengthy study. We would have to examine any proposal carefully to be sure that we had a meaningful agreement with regard to technology transfer and so forth.

The CHAIRMAN. Let me interrupt again, if I may. When he says we propose, he is not speaking for the Supreme Soviet even though he is a member of that.

But he goes on to say that, "I have had the opportunity to explain the position of the Supreme Soviet on the issue of the CSS," that is the space group of which he is director, "on the issue of the future use of nuclear power in space to high officials of the Ministry of Foreign Affairs of the USSR."

He does not say what the response is, so this is not an official government position of the Soviet Union, saying that he wants to ban space missions. Because of course, they have RORSATs, of which Cosmos 1900 is one that is orbiting even as we speak. But he does at least propose that for himself.

Senator BUMPERS. Mr. Chairman, I will not belabor this issue any longer.

I simply want to say that I appreciate your very articulate testimony, all of you, on the safety precautions that you are taking in the satellites that we have launched and the satellites that we will launch.

And obviously, an SP–100, you are talking about the mid-1990s. It is my fervent hope that not only will SDI not go forward, but that if it does go forward, it will not go forward with nuclear power plants.

And I do not care how much safety—God knows the Challenger had every kind of a safety precaution we thought that man could think up. And so you know that the best-made plans go awry. I do not care how much safety you put into these things.

And I might also conclude by saying, SDI is still very popular in this country. Every poll shows it. The President plays it like a pipe organ.

But when you tell the American people, and I am just as certain as I am sitting here, when you tell the American people that that system is going to be activated, they are going to be powered by a multi-megawatt, several multi-megawatt nuclear power plants in space, when that word begins to filter down to the American people, there is going to be a tremendous dampening of enthusiasm for this project. Thank you, Mr. Chairman.

The CHAIRMAN. Thank you. Mr. Bitz, suppose that Academician Sagdeev did speak for the Soviet Union, and was giving the official position of that country, that we should ban nuclear power systems in space, and you were to give the response of the United States, what would your advice be?

Mr. Bitz. Well, as I said a few moments ago, Senator, my response is that it may have merit and could be examined.

But beyond that point I do not think I have an official position to express. This is a matter that gets into the area of international affairs.

Dr. Rosen. Senator, I would like to respond. As I said in my testimony, we have several potential missions which nuclear reactors would have a very dramatic enhancing effect. And to go ahead and ban nuclear reactors——

The Chairman. Deep space missions, you are talking about.

Dr. Rosen. Deep space missions as well as lunar missions, as well as some potential missions in relatively low earth orbit.

The Chairman. Well, now, he seems to be exempting that in his proposal, that international cooperation on deep space missions and small isotopes, would you need more than small isotopes for any of those missions?

Dr. Rosen. Well, as I said earlier, for nuclear electric propulsion systems, you would need reactors.

For an operating base on the moon, or at some point in time in the future when we have a base on Mars, they will require large amounts of power. And RTGs simply would not do it.

It is not clear that we can be effective with solar systems as well, simply because of the energy storage requirements on the moon, or the distance that Mars is from the sun, if the base is on Mars.

So in those kinds of circumstances, I think to have placed a ban on nuclear reactors would give us great difficulty.

If you talk about low earth orbit, it is not clear today that we have an absolute requirement in low earth orbit. But there are several potential applications that we have looked at, which are very, very encouraging.

I mentioned earlier the materials processing, at some point in time there is a tremendous potential, we believe, for processing materials in low earth orbit. There is a commercial potential there.

The Chairman. In the space station?

Dr. Rosen. I did not say the space station, Senator. But in a generic space station, in some space station in low earth orbit.

And it is not clear to me how we could process large amounts of material in orbit without having large amounts of power. And one option for that, not the only option but one option, would be a nuclear power source.

It may be that when the time comes that that is not an acceptable option. But I would be reluctant at this point in time to ban those kinds of systems and foreclose our looking at those kinds of options.

Colonel Hess. Sir, if I may, in the final analysis, I believe this issue should be resolved on the basis of a detailed risk versus benefit assessment.

I believe when such an assessment is made, and the benefits are weighed against the risks, that the American people will make the right choice as to whether or not space nuclear power systems should be permitted and flown by this country.

There is some risk when I leave this hearing that I will be struck by an automobile. However, that does not lead to efforts to ban motor vehicles from this nation. Due to such a detailed assessment of the benefits, clearly outweigh the risks.

I think such an assessment is appropriate here, and we would welcome an opportunity to expose any analysis to that kind of reasoning.

Senator BUMPERS. Col. Hess, I heard Jay Leno, the comedian, say one time about the analogy you just gave about getting hit by a car, and equating that with nuclear accidents. He said, there is one thing about it, they do not tell you not to eat the vegetables when you get hit by a car.

The CHAIRMAN. All right, Col. Hess, you state that there are alternatives to nuclear power for SDI.

Suppose the House came up with language that prohibited nuclear space systems for use in SDI, and that bill came over to us, and we were to appear as the Senate conferees on that. What would be your response?

Would you say, well, that is okay, we have got an alternative to that?

Colonel HESS. Sir, we would not think that that would be a wise choice. But should such legislation pass, we would defer to the will of the Congress obviously.

We do not believe that to be the correct thing to do. We believe that the benefits outweigh the risks. Clearly for the initial systems there are no plans to use space nuclear power sources.

It would, as I stated, cause advance systems, follow-on systems to be less cost-effective, and perhaps not affordable, as you suggested.

The CHAIRMAN. Well, let me read you from this article, this is from the Albuquerque Journal of Tuesday, January 12, 1988.

"Failure to develop nuclear power in space could cripple efforts to deploy anti-missile sensors and weapons in orbit," Abrahamson told the University of New Mexico Symposium on Space Nuclear Systems.

"Without orbits in space, that is going to be a long, long light cord that goes down to the surface of the earth," he added.

Colonel HESS. Sir, I believe the operative word is "could" as opposed to—it would be disastrous.

The CHAIRMAN. So obviously you agree with General Abrahamson.

Colonel HESS. Well, yes sir.

Senator BUMPERS. I could just see those colonel's wings coming off now.

The CHAIRMAN. Really what he is saying is that is the only way to do it. That is the real answer, whether you want to say it or not. That is the answer, unless you want to have this long light cord up in space.

A light cord that long would be hard to maintain up there, would it not?

Colonel HESS. The logistics would be difficult, sir.

The CHAIRMAN. Before this panel goes, I simply want to make clear that there is a vast difference in American nuclear power systems in space and those of the Soviet Union.

There are inherent differences that are due to the higher orbit, and I think that ours are light-years safer than theirs. Now, whether or not they should be deployed with respect to SDI is another question. But I think this panel has clearly established that fact.

Gentlemen, thank you very much. You have been a very good panel.

Our next panel is composed of Steven Aftergood, Executive Director of the Committee to Bridge the Gap from Los Angeles, California, and Mr. Daniel Hirsch, Director of the Stevenson Program on Nuclear Policy of the University of California at Santa Cruz. He represents the Federation of American Scientists.

If you gentlemen would please come forward. Mr. Hirsch, I know you are going to read Mr. Sagdeev's statement, but I think we have enough of that statement in the record now. Let us begin with Mr. Aftergood.

STATEMENT OF STEVEN AFTERGOOD, EXECUTIVE DIRECTOR, COMMITTEE TO BRIDGE THE GAP

Mr. Aftergood. Thank you. My name is Steven Aftergood. I am Director of the Committee to Bridge the Gap, a public interest group in Los Angeles that specializes in studying space nuclear power technology and policy. I appreciate the opportunity to be here today.

To fully grasp the significance of the continuing fall of Cosmos 1900, I think it needs to be seen in the context of the numerous accidents and failures involving space nuclear power that have preceded it over the last 25 years.

Viewed in this broader perspective, Cosmos 1900 appears as part of a pattern of accidents——

The Chairman. May we please have order?

Mr. Aftergood. Cosmos 1900 is part of a pattern of accidents that have recurred on an almost regular basis in both the U.S. and Soviet space nuclear power programs.

Each of these incidents, major and minor, is listed in my written testimony. I would just briefly mention two of the most serious, the first being in 1964 when a U.S. navigational satellite powered by a plutonium RTG, or heat source, suffered a launch failure.

The plutonium power supply disintegrated in the atmosphere, settling as fallout throughout the world over the next several years. There was enough plutonium in this one power source to triple the worldwide inventory of the isotope plutonium-238, which had remained from atmospheric weapons tests.

The Chairman. While you are at that point, would you like to tell us the difference between irradiated fuel and non-irradiated fuel with respect to safety?

Mr. Aftergood. Well, that difference pertains to the use of uranium fuel, which is used in reactors.

Fresh un-irradiated uranium is not very highly-radioactive. You can pick it up in your hand if you need to and nothing too serious is going to happen.

It is only after it has been irradiated that you get the radioactive fission products, which are byproducts of operation and which are highly-radioactive. That all applies to the use of uranium fuel in reactors.

However, the use of plutonium, specifically the isotope plutonium-238 in RTGs, these plutonium heat sources, that distinction does not apply, because plutonium-238, unlike uranium, is very highly-radioactive.

And in fact it is continuously decaying, so it is always operating. So there is no pre- or post-operational distinction there.

The lesson that I think is to be learned from this history of accidents is not that these various incidents were necessarily great catastrophes, most of them were not. The lesson the history rather is that as a whole there is a pattern of recurring accidents, with the continuation of the space nuclear power programs, we can be virtually certain that that pattern of failures, large and small, will continue into the future.

Now, you have to ask how dangerous are accidents involving space nuclear power? The extraordinary fact here is that the U.S. Department of Energy does not want the public to know the answer to that question.

It is not that official consequence estimates do not exist. They exist, but they are classified. When Chairman Johnston, when you asked the question earlier, you got what was essentially a non-responsive answer, and the same thing when Senator Bumpers asked, what is going to happen—assume a worst case, what is going to happen? You also got a non-responsive answer.

I learned of a document that provided generic or consequence estimates for accidents involving generic space reactors. No detailed design information, no intelligence information, just calculations of estimates from generic accidents, including one which resembled a typical RORSAT mission.

I asked for it under the Freedom of Information Act. The request was denied. In the letter of denial, the Department of Energy wrote that release of this information "could reasonably be expected to cause damage to the national security."

In other words, it seems to be DOE's position, if the public understood the risks that it is now actually facing from Cosmos 1900, national security would be threatened. This in my opinion is absurd, fundamentally wrong, and symptomatic of the lack of public accountability in the space nuclear power program.

In the absence of any official consequence estimate, we have provided a somewhat crude estimate described in my written testimony. We took another consequence estimate from a DOE contractor study for a slightly larger reactor and extrapolated it down to the conditions roughly estimated of Cosmos 1900.

What we found is that a maximum of a couple of hundred fatal cancers could result from a hypothetical worst case involving a reactor like the one aboard Cosmos 1900. This I have to say is not a prediction, but it is more a reflection of how much radioactivity is present in the reactor at the end of operation.

The actual consequences depend on particle size, distribution, and other aspects of the exposure pathway, and could in fact, and hopefully will be as low as zero fatal cancers.

Whatever the potential consequences may be, they are likely to increase dramatically in future accidents involving space nuclear power, along with the enormous increase in power level and operating lifetime in the next generation of nuclear power supplies.

The U.S. SP–100 reactor now under development, for example, will contain several hundred times more long-lived radioactivity at the end of its seven-year lifetime than the Cosmos 1900 does today. So the consequences, given an accident involving the SP–100, could be proportionately greater.

If the steady 15 percent accident rate that has occurred so far were to continue into the future, we are going to have some very severe nuclear accidents.

The distinctions in U.S. and Soviet space nuclear safety policy unfortunately may not be as great as have been suggested earlier. For one thing is the difference in power level I mentioned.

The U.S. reactors of the future are going to have a much larger radioactive inventory than the Soviet reactors of the present. That is one factor that influences safety.

Another factor is the question of the height of the altitude. DOE officials had previously pledged, and there is a citation in my written testimony, to deploy nuclear power sources only in what they called a nuclear-safe orbit.

That is an orbit that is sufficiently long-lived so that much of the radioactivity in the reactor would decay before reentry could possibly occur. Unfortunately, that pledge to adhere to a nuclear-safe orbit has been abandoned.

Since there is no significant public or Congressional oversight of space nuclear power, this change has gone largely unnoticed.

But if you were listening very closely this morning, you may have noticed that Mr. Bitz of the Department of Energy stated that most U.S. nuclear power supplies would be deployed at an orbit that would continue for several hundred years or longer. Most but not all.

Similarly, Dr. Rosen of NASA indicated that in fact they do want, they do have potential missions that could be in quite low orbits and require boosting further up. Without saying so explicitly, the space nuclear power programs are reserving the option to operate in a low orbit as the Soviets are currently doing.

Now, risk is not necessarily a bad thing. I think Col. Hess had it exactly right. To make risk-avoidance a top priority is a neurotic trait, not a rational one. But a responsible person will minimize unnecessary risks and waive them against the benefits to be gained.

The problem with space nuclear power is that in the near term, in my opinion, the benefits of it may be as bad or worse than the risks.

By that I mean the fact that the primary near-term applications of nuclear power, particularly in orbit, are for military applications that are provocative, and potentially strategically destabilizing.

The Soviet RORSAT program is a perfect example of this. Although Col. Culbertson was not willing to say so, other Air Force officials have acknowledged that RORSATs are used to track and target U.S. naval vessels, and they have cited these systems as a principal justification for a U.S. anti-satellite capability.

The CHAIRMAN. Cosmos 1900 is of that kind, is it not, in your view?

Mr. AFTERGOOD. That has not been officially confirmed. But it has been unofficially confirmed because it fits the typical mission profile, and it is hard to imagine what else it might be. So all but officially it has been confirmed. And the citation for the Air Force consideration of these RORSATs as a threat is also given in my written testimony.

The primary U.S. application in the near-term is for SDI, which is of course viewed as a provocation and a threat by the Soviet Union.

The deployment of dozens of nuclear-powered SDI weapons platforms would be a major environmental hazard as well as a strategic provocation.

I want to note that the question of applications and the provocative nature of these systems is entirely independent of their environmental hazard. A safe RORSAT would still be a strategic problem, if it is inducing us to develop an anti-satellite weapon.

We do recognize that nuclear power has made a positive contribution in the past, and may well do so in the future. We know, however, that virtually all of the civilian applications have been in deep space missions.

And similarly, the overriding majority of the future civilian applications will be beyond geosynchronous orbit. Lunar missions, Mars base's propulsion for deep space, and so on.

We believe that this provides a useful way of distinguishing between the constructive and the provocative applications of space nuclear power, and in fact this distinction is implicit in the Federation of American Scientists and Soviet scientists' proposal for a ban that would restrict nuclear power in orbit.

It would not interfere with just about all of the missions described by Dr. Rosen for NASA's next century.

The CHAIRMAN. If I may interrupt you at that point, we presently have a ban on nuclear weapons in space, and phase one of SDI would not require nuclear reactors. So would not another treaty really just be redundant, unnecessary? The ABM Treaty as well prohibits that.

Mr. AFTERGOOD. Well, the mechanics of a treaty may be unnecessary. I believe an agreement is warranted on its merits.

In addition, I believe that a ban on nuclear power in orbit could strengthen the ABM Treaty in a modest way, because to the extent that many advanced directed energy weapons require nuclear reactors, it would make such a ban more verifiable.

In other words, it is easier to detect reactors on a weapons platform than it might be to determine the nature of the platform itself. So a ban on reactors in orbit could increase the verifiability of a ban on weapons in space.

But I think that needs to be, you know, explored further. Maybe there are informal ways of doing it that are just as effective.

The CHAIRMAN. Well, really, on a more fundamental level, the next administration, whichever it is, is simply going to have to decide whether the ABM Treaty is made viable, or whether we get into a space race. That is the fundamental question.

The ABM Treaty is meant to prohibit that space race, and either it is going to be adhered to and fleshed out insofar as SDI is concerned, or it is going to be scrapped. Is that not really the fundamental question?

Mr. Aftergood. I would agree with that, yes. I would just conclude with one last observation, and that is that there is an ethical problem with the use of space nuclear power in orbit.

And that has to do with the fact that the people who bear the risks, which is potentially the entire world population, have no say whatsoever in these deployment and development decisions.

The U.S. and the Soviet Union are making their decisions about policy as if they are the only people who are involved. And the reality, as we have seen before, and unfortunately we are likely to see again, is that they are not. Everybody is at risk. Thank you.

[The prepared statement of Mr. Aftergood follows:]

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Statement of

Steven Aftergood
Executive Director
Committee to Bridge the Gap

on Cosmos 1900 and the Future of Space Nuclear Power

Before the

Committee on Energy and Natural Resources
United States Senate

September 13, 1988

My name is Steven Aftergood. I am Executive Director of the Committee to Bridge the Gap, a public interest research organization based in Los Angeles that has been monitoring space nuclear power programs for several years. I appreciate the opportunity to appear at this hearing to present our views on space nuclear power.

Though the impending reentry of the nuclear-powered Cosmos 1900 satellite provides the immediate occasion for today's hearing, the questions raised by the use of nuclear power in space go beyond the details of this particular incident. The fall of Cosmos 1900 is simply the latest episode in a series of recurring accidents. Beyond the environmental hazards of such incidents, the primary applications of nuclear power in orbit are in themselves a provocation and a threat. The large nuclear power sources now under development will exacerbate both the environmental and military dangers of space nuclear power. We therefore support a ban on the use of nuclear power in orbit that would minimize those hazards while permitting the peaceful use of nuclear power in future deep space missions.

Past U.S. and Soviet Launches of Nuclear-Powered Spacecraft

The Soviet Union and the United States have launched dozens of nuclear power supplies. The Soviet Union has relied primarily on nuclear reactors, while the United States has mainly used radioisotope thermoelectric generators (RTGs) fueled by plutonium-238.

Between 1961 and 1977, the U.S. has launched a total of 23 spacecraft powered by more than three dozen RTGs and one nuclear reactor. These launches are listed in Table 1.

The Soviet Union has launched more than 30 nuclear reactor-powered satellites and several RTG-powered satellites and lunar modules. A list of nuclear-powered spacecraft launched by the USSR is given in Table 2.

Both the US and USSR Have Suffered Accidents Involving Space Nuclear Power

A disturbingly large fraction-- about 15%-- of all nuclear powered spacecraft in both the U.S. and Soviet space programs have suffered accidents, launch aborts, or other failures. These incidents are briefly described below in chronological order:[1]

- 1964: When the U.S. Transit-5BN-3 navigational satellite failed to achieve orbit on April 21, its SNAP-9A RTG power source disintegrated in the atmosphere at an altitude of about 50 kilometers. Release of its 17,000 Curies of plutonium-238 tripled the worldwide inventory of Pu-238 and increased the total world environmental burden (measured in Curies) from all plutonium isotopes, produced primarily from atmospheric weapons testing, by about 4%.[2]

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[1] S. Aftergood, "Nuclear Space Mishaps and Star Wars," Bulletin of the Atomic Scientists, October 1986, pp. 40-43.

[2] E.P. Hardy, P.W. Krey, and H.L. Volchok, "Global Inventory and Distribution of Fallout Plutonium," Nature, February 16, 1973, p. 444.

- 1965: On April 3, the U.S. Snapshot experimental satellite was launched, bearing the only space reactor put into space by the U.S., a 500 Watt SNAP-10A. The reactor functioned for 43 days before being permanently shut down by a voltage regulator malfunction. While it remains in a long-lived orbit, portions of the satellite have begun to break up.[3]

- 1968: On May 18, the U.S. Nimbus-B-1 meteorological satellite was aborted following a launch failure, and fell into the Pacific Ocean just off the California coast. Its two SNAP-19A RTGs could not be located for five months but were finally retrieved intact.

- 1969: A Soviet launch failure occurred on January 25 that may have involved a nuclear-powered RORSAT.

- 1969: On September 23 and October 22 the U.S.S.R. launched unmanned probes to the Moon. Both achieved Earth orbit, but reentered the atmosphere a few days later. According to various sources, one or both of them carried a ^{210}Po heat source, and measurable amounts of radioactivity were detected in the atmosphere following reentry.[4]

- 1970: A U.S. moon mission, Apollo 13, was aborted in April. Its jettisoned lunar lander fell into the Pacific Ocean. The SNAP-27 plutonium power supply has never been recovered, but is assumed to have remained intact.

- 1973: On April 25, another Soviet nuclear-powered RORSAT fell into the Pacific Ocean north of Japan after a launch failure.

- 1978: The Soviet Cosmos 954 reentered the atmosphere on January 24, spreading thousands of pieces of radioactive debris over more than 100,000 square kilometers of northwest Canada.[5] Some fragments were highly radioactive (gamma radiation as high as 500 roentgen per hour near contact).

- 1983: The jettisoned reactor core from the Cosmos 1402 fell out of orbit on February 7, disintegrated and was dispersed in the atmosphere.[6]

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[3] Nicholas L. Johnson, Darren S. McKnight, Artificial Space Debris, Orbit Book Company, Malabar FL, 1987, page 91.

[4] William J. Broad, "Satellite's Fuel Core Falls 'Harmlessly'," New York Times, February 8, 1983, pp. C1, C2.

[5] W.K. Gummer, et al, "Cosmos 954: The Occurrence and Nature of Recovered Debris," (Hull, Quebec: Canadian Government Publishing Center, INFO-0006, May 1980), page 11.

[6] Robert Leifer, et al, "Detection of Uranium from Cosmos-1402 in the Stratosphere," Science, vol. 238, 23 October 1987, pp. 512-3.

- 1988: Radio contact with Cosmos 1900 was lost in April of 1988, preventing boost of the satellite to a high altitude disposal orbit. Various backup systems have thus far failed to function. Atmospheric reentry, resulting in partial or complete disintegration of the on-board reactor, is expected in September or October.[7]

Public Health Consequences of the Reentry of Cosmos 1900

DOE has until now refused[8] to disclose information on the range of possible fatalities from reentry of the Cosmos 1900. But these can nevertheless be crudely estimated.

For simplicity, one may begin with a related estimate from a Department of Energy contractor study that as many as 30,000 to 50,000 fatal cancers could possibly result from reentry and complete disintegration of a 1000 kilowatt-thermal reactor during operation or immediately upon shutdown following 10 years of continuous operation at full power.[9]

Extrapolating from the DOE contractor estimate to the conditions of Cosmos 1900 yields a maximum of several hundred fatal cancers. This assumes optimum (i.e. worst case) distribution and exposure. In the best case, there would be little or no opportunity for public exposure, and zero fatalities would result.

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[7] W.J. Broad, "Soviet Nuclear-Powered Satellite Expected to Hit Earth in Summer," New York Times, May 14, 1988.

[8] The Dept of Energy refused a Freedom of Information Act request to release a document that presents public health consequence estimates for various generic space nuclear power missions, including one analogous to Cosmos 1900. DOE claimed incredibly that release of these consequence estimates "could reasonably be expected to cause damage to the national security." See 2/1/88 letter from Dennis A. Bitz to S. Aftergood, denying release of most of NUS Report 4083, Rev. 1, "Comparative Risk Analysis of Selected Missions Utilizing Space Nuclear Electric Power Systems."

[9] B.W. Bartram, D.W. Pyatt, "Safety Assessment for Space Reactors," NUS-3442, December 1979, pp. 27, 51.

Risks Will Increase with Use of Large New Nuclear Power Supplies

The U.S. has several space nuclear power development programs underway. These include the SP-100 reactor, designed to provide 100 kilowatts of electricity continuously for 7 years; the Multimegawatt Program, that is researching reactors capable of generating tens to hundreds of Megawatts; and the Dynamic Isotope Power System (DIPS), a radioisotope heat source with dynamic energy conversion to provide 1 to 10 kilowatts.

The new generation of nuclear power supplies represents a very large increase in power level and operating lifetime-- and hence in associated risk-- over past and current systems.

Thus, for example, at the end of its seven year operating lifetime, the SP-100 will contain several hundred times more long-lived radioactivity than the Cosmos 1900. While a worst case accident involving Cosmos 1900 could potentially produce hundreds of fatal cancers, there is sufficient radioactivity in an SP-100 to cause tens of thousands of fatal cancers, using the assumptions of the DOE contractor study cited above.

One single DIPS radioisotope system at a power level of 6 kilowatts will contain over 50 times more plutonium-238 than did the SNAP 9A that disintegrated in 1964. Put another way, one DIPS unit will contain two and a half times more plutonium (measured in Curies) than in all of the plutonium fallout from all atmospheric nuclear weapons tests.

Of course, the risks of nuclear-powered space missions can be partially reduced by proper design, judicious deployment, and good luck. But the growth of the new space nuclear power systems will raise the consequences of continued failures enormously.

The Applications of Nuclear Power in Orbit Are Themselves a Threat

Beyond the environmental risks of space nuclear power, this technology is also dangerous because of its expanding role in provocative military space systems.

This danger is already evident in the current use of nuclear reactors to power Soviet Radar Ocean Reconnaissance Satellites (RORSATs), such as Cosmos 1900, that track and target U.S. naval vessels. These satellites are deemed sufficiently threatening to U.S. national security that they have been cited by the Pentagon as a principal justification for a U.S. anti-satellite weapon program.[10]

It should be noted that this threat is entirely independent of the environmental hazard. Even if space nuclear power could be made risk-free and accident-proof, an environmentally safe RORSAT would still be a dangerous provocation.

A parallel situation exists with regard to space nuclear power programs in the U.S., which are driven by plans to deploy military platforms, including SDI systems, in orbit, and are viewed by the Soviets as a strategic threat.[11]

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10. as noted by Nicholas L. Johnson in The Soviet Year in Space 1985, Teledyne Brown Engineering, page 39. See also U.S. Department of Defense, Soviet Military Power 1985, page 53; and "USAF Official Calls Soviet Satellites Threat to U.S. Carrier Battle Groups," Aviation Week & Space Technology, September 29, 1986, page 20.

11. See, e.g., Y. Zhukov, "Nuclear Reactors for SDI," Pravda, November 12, 1986.

Space Nuclear Power for Star Wars

The Strategic Defense Initiative (SDI) is the central motivating factor in the U.S. space nuclear power program. Without SDI, there is little or no demand in the near term for the type of space nuclear power supplies now being developed. In the words of a senior Department of Energy official:[12]

> ...I would say that, frankly speaking, the major rebirth and driving factor [for the space reactor program] is the President's strategic defense initiative. I think if it were not for that, we would be hard pressed to have a sufficient number of defined missions to sustain it at the levels we're talking about today.

There seems to be a broad consensus that nuclear power would be required for many types of Star Wars weapons. Thus, the American Physical Society Study Group on Directed Energy Weapons indicated that "perhaps a hundred or more" orbiting reactors might be needed in a fully deployed space-based weapons systems.[13] A similar conclusion was reached recently by the Office of Technology Assessment.[14] And Lt. Gen. James Abrahamson has stated that space reactors will be an essential component of the second phase of SDI.[15]

In sharp contrast to the prominence of space nuclear power in controversial military space projects such as the RORSAT program and SDI, it has few near-term applications for more benign, peaceful endeavors.

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[12] testimony of James W. Vaughan, Jr., then Acting Ass't Secretary for Nuclear Energy, DOE, in "Space Nuclear Power, Conversion and Energy Storage for the Nineties and Beyond," hearings before the Subcommittee on Energy Research and Production, Committee on Science and Technology, U.S. House of Representatives, October 1985, page 68.

[13] Reviews of Modern Physics, vol. 59, No. 3, Part II, July 1987, p. S169.

[14] SDI: Technology, Survivability, and Software, OTA-ISC-353, May 1988, p. 155.

[15] B. Spice, "SDI Looks to Nuclear Power," Albuquerque Journal, January 12, 1988, p. A1.

In particular, there is no commercial interest in nuclear-powered satellites, according to one commercial space consultant, due to concerns about accident liability and launch expense: "Very few people want to mess with it."[16]

The Use of Nuclear Power in Space is Virtually Unregulated

Despite the extensive history of accidents involving space nuclear power, there is no international regulatory mechanism to effectively prevent the recurrence of these incidents. The United Nations Committee on Peaceful Uses of Outer Space established a Working Group to consider safety guidelines for space nuclear power following the reentry of Cosmos 954. Ten years later, however, a similar accident is in progress, and the Working Group might as well never have existed.

This absence of effective regulation is also evident within the United States, where the various space nuclear power development programs are largely insulated from any oversight outside of the sponsoring agencies.

Unlike the case of commercial nuclear power plants, there is no licensing procedure for space nuclear power. This means that there is no official forum for public scrutiny of design and deployment decisions, no opportunity for cross examination of expert witnesses, and no impartial review before an independent, disinterested panel of judges.

The distinction between a licensed and an unlicensed reactor is not just a legal one. Often, the fact that a reactor is unlicensed means that it is not safe enough or not operated with sufficient rigor to get a license. The poor environmental record of the Department of Energy's

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16. Walter Morgan of the Communications Center in Clarksburg, Maryland, quoted in Satellite Communications, August 1988, p. 13.

unlicensed nuclear facilities, the 1987 National Academy of Sciences critique of DOE´s production reactors, and DOE´s own admission that its reactors generally could not meet the safety standards of the Nuclear Regulatory Commission all testify to the failures of an unregulated nuclear power program.

It is true that space nuclear power designs and missions are reviewed in some depth by the Interagency Nuclear Safety Review Panel (INSRP) which produces the Safety Evaluation Report (SER) for each mission, and INSRP´s function is often described as "independent oversight." In fact, however, INSRP is composed of representatives of the sponsoring agencies-- the Department of Energy, NASA, and the Department of Defense-- which may create a certain conflict of interest. What makes matters worse is that INSRP´s meetings and deliberations are closed. All INSRP documents short of the final SER are classified. So in effect, the only thing INSRP is "independent" of is the public!

DOE Has Abandoned the Nuclear Safe Orbit Standard

The lack of sustained Congressional oversight and the exclusion of the public from any significant role in the space nuclear power programs have already yielded some dubious policy decisions within these programs.

One example is the disavowal of the "nuclear safe orbit" criterion. Such an orbit is one sufficiently high to allow radioactive decay of some large percentage of the fission and activation products prior to reentry. Department of Energy officials had publicly pledged[17] to adhere to this standard:

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[17] Testimony of Stephen Lanes, Director, DOE Office of Defense Energy Projects, in "Space Nuclear Power, Conversion and Energy Storage for the Nineties and Beyond," Committee on Science and Technology, U.S. House of Representatives, October 1985, p. 67.

> ...we will not start it [a reactor] up until it achieves what we call a nuclear safe orbit, that is, an orbit that is long-lived enough such that the fission products will decay to a relatively safe level before that orbit decays and the device could possibly reenter and burn up in the atmosphere.

Around January 1987, however, the "nuclear safe orbit" commitment was quietly abandoned. While the "nuclear safe orbit" would not fully resolve environmental concerns about space nuclear power, much less the strategic hazards, the rescinding of this minimal safety standard is discouraging.

Conclusion: Prohibit the Use of Nuclear Power in Orbit

Given the continuing potential for a serious accident, the current and anticipated role of nuclear power in provocative military space systems, the dearth of civilian applications for nuclear powered satellites, and the absence of commercial interest in such satellites, one must ask: are we better off with or without space nuclear power?

It should be acknowledged that there is a positive aspect to space nuclear power. The Pioneer and Voyager planetary missions, for example, have made a valuable contribution to space science and represent a constructive element of U.S. space policy that ought to be encouraged. Though missions like these have risks which must be minimized, they offer benefits to weigh against those risks.

But it is noteworthy that these and nearly all other civilian applications of space nuclear power contemplated for the next century are for missions beyond geosynchronous orbit.

The distinction between orbital and deep space applications provides a practical criterion for distinguishing between civilian missions and the more controversial, threatening, and environmentally hazardous military missions.

This distinction is implicit in the recent proposal by the Federation of American Scientists and the Committee of Soviet Scientists headed by Roald Sagdeev to ban the use of nuclear power in orbit.[18] We believe that this proposal offers a middle path that would eliminate the more threatening current and proposed applications of nuclear power in orbit, while preserving the option of using nuclear power for deep space scientific and exploratory missions.

It is important to recognize that the status quo of one space nuclear accident every few years is about to change. If orbital applications of space nuclear power are not restricted, the deployment of nuclear-powered military satellites could increase sharply, along with the power level of the nuclear power supplies, and the magnitude of the resulting accidents.

We believe that everyone, including the majority of world's population that bears the risks yet has no say in this matter, would be better off if nuclear power in orbit were banned.

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[18] Frank von Hippel (Federation of American Scientists) and Roald Sagdeev (Committee of Soviet Scientists Against the Nuclear Threat), "A Joint Proposal to Ban Nuclear Power in Earth Orbit," May 13, 1988; see also Theresa M. Foley, "Soviet, U.S. Scientists Urge Ban on Nuclear Powered Satellites," Aviation Week & Space Technology, June 6, 1988, p. 48; W.J. Broad, "Soviet Nuclear-Powered Satellite Expected to Hit Earth in Summer," New York Times, May 14, 1988; David C. Morrison, "Space Nukes," National Journal, June 4, 1988, page 1511.

Table 1: Space Nuclear Power Systems Launched by the U.S.[19]

Power Source	Spacecraft	Mission type	Launch date	Status
SNAP-3A	TRANSIT 4A	navigational	June 29, 1961	in orbit
SNAP-3A	TRANSIT 4B	navigational	Nov 15, 1961	in orbit
SNAP-9A	TRANSIT-5BN-1	navigational	Sept 28, 1963	in orbit
SNAP-9A	TRANSIT-5BN-2	navigational	Dec 5, 1963	in orbit
SNAP-9A	TRANSIT-5BN-3	navigational	Apr 21, 1964	aborted
SNAP-10A (reactor)	SNAPSHOT	experimental	Apr 3, 1965	in orbit
SNAP-19B2	NIMBUS-B-1	meteorological	May 18, 1968	aborted
SNAP-19B3	NIMBUS III	meteorological	Apr 14, 1969	in orbit
SNAP-27	APOLLO 12	lunar	Nov 14, 1969	on lunar surface
SNAP-27	APOLLO 13	lunar	Apr 11, 1970	aborted
SNAP-27	APOLLO 14	lunar	Jan 31, 1971	on lunar surface
SNAP-27	APOLLO 15	lunar	July 26, 1971	on lunar surface
SNAP-19	PIONEER 10	planetary	Mar 2, 1972	beyond Pluto
SNAP-27	APOLLO 16	lunar	Apr 16, 1972	on lunar surface
TRANSIT-RTG	TRANSIT-01-1X	navigational	Sept 2, 1972	in orbit
SNAP-27	APOLLO 17	lunar	Dec 7, 1972	on lunar surface
SNAP-19	PIONEER 11	planetary	April 5, 1973	beyond Saturn
SNAP-19	VIKING 1	Mars	Aug 20, 1975	on Mars
SNAP-19	VIKING 2	Mars	Sept 9, 1975	on Mars
MHW	LES 8	communications	Mar 14, 1976	in orbit
MHW	LES 9	communications	Mar 14, 1976	in orbit
MHW	VOYAGER 2	planetary	Aug 20, 1977	beyond Uranus
MHW	VOYAGER 1	planetary	Sept 5, 1977	beyond Saturn

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19. Based on Gary L. Bennett, James J. Lombardo, and Bernard J. Rock, "Development and Use of Nuclear Power Sources for Space Applications," _Journal of the Astronautical Sciences_, Vol. XXIX, No. 4, pp. 321-342, October-December 1981.

Table 2: Nuclear Powered Spacecraft Launched by the USSR[20]

Name	Launch Date	Fuel	Mean Altitude	Mission Duration
Cosmos 84 (RTG)	3 Sept 1965	$^{210}\mathrm{Po}$?	1500 km	
Cosmos 90 (RTG)	18 Sept 1965	$^{210}\mathrm{Po}$?	1500	
Cosmos 198	27 Dec 1967	$^{235}\mathrm{U}$	920	1 day
Cosmos 209	22 Mar 1968	$^{235}\mathrm{U}$	905	1 day
---	25 Jan 1969	(possible RORSAT launch failure)		
Cosmos 300	23 Sept 1969	$^{210}\mathrm{Po}$?	reentered	
Cosmos 305	22 Oct 1969	$^{210}\mathrm{Po}$?	reentered	
Cosmos 367	3 Oct 1970	$^{235}\mathrm{U}$	970	1 day
Cosmos 402	1 Apr 1971	$^{235}\mathrm{U}$	990	1 day
Cosmos 469	25 Dec 1971	$^{235}\mathrm{U}$	980	9 days
Cosmos 516	21 Aug 1972	$^{235}\mathrm{U}$	975	32 days
---	25 Apr 1973	(RORSAT launch failure)		
Cosmos 626	27 Dec 1973	$^{235}\mathrm{U}$	945	45 days
Cosmos 651	15 May 1974	$^{235}\mathrm{U}$	920	71 days
Cosmos 654	17 May 1974	$^{235}\mathrm{U}$	965	74 days
Cosmos 723	2 Apr 1975	$^{235}\mathrm{U}$	930	43 days
Cosmos 724	7 Apr 1975	$^{235}\mathrm{U}$	900	65 days
Cosmos 785	12 Dec 1975	$^{235}\mathrm{U}$	955	1 day
Cosmos 860	17 Oct 1976	$^{235}\mathrm{U}$	960	24 days
Cosmos 861	21 Oct 1976	$^{235}\mathrm{U}$	960	60 days
Cosmos 952	16 Sept 1977	$^{235}\mathrm{U}$	950	21 days
Cosmos 954	18 Sept 1977	$^{235}\mathrm{U}$	reentered	~43 days
Cosmos 1176	29 Apr 1980	$^{235}\mathrm{U}$	920	134 days
Cosmos 1249	5 Mar 1981	$^{235}\mathrm{U}$	940	105 days
Cosmos 1266	21 Apr 1981	$^{235}\mathrm{U}$	930	8 days
Cosmos 1299	24 Aug 1981	$^{235}\mathrm{U}$	945	12 days
Cosmos 1365	14 May 1982	$^{235}\mathrm{U}$	930	135 days
Cosmos 1372	1 June 1982	$^{235}\mathrm{U}$	945	70 days
Cosmos 1402	30 Aug 1982	$^{235}\mathrm{U}$	reentered	120 days
Cosmos 1412	2 Oct 1982	$^{235}\mathrm{U}$	945	39 days
Cosmos 1579	29 June 1984	$^{235}\mathrm{U}$	945	90 days
Cosmos 1607	31 Oct 1984	$^{235}\mathrm{U}$	950	93 days
Cosmos 1670	1 Aug 1985	$^{235}\mathrm{U}$	950	83 days
Cosmos 1677	23 Aug 1985	$^{235}\mathrm{U}$	940	60 days
Cosmos 1736	21 Mar 1986	$^{235}\mathrm{U}$	960	92 days
Cosmos 1771	20 Aug 1986	$^{235}\mathrm{U}$	960	56 days
Cosmos 1860	18 June 1987	$^{235}\mathrm{U}$	950	40 days
Cosmos 1900	12 Dec 1987	$^{235}\mathrm{U}$	reentering	~124 days
Cosmos 1932	14 March 1988	$^{235}\mathrm{U}$	965	66 days

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[20] Based on Nicholas L. Johnson, "Nuclear Power Supplies in Orbit," *Space Policy*, August 1986, pp. 227, 228. Revised and updated by personal communication with N.L. Johnson, June 24, 1988. Mean altitude refers to disposal altitude and is given as of 1 January 1986 for pre-1986 launches. Initial deployment altitude for RORSATS is typically around 250 km. Polonium-210 has a half-life of 138.39 days.

The CHAIRMAN. Thank you very much, Mr. Aftergood.

Mr. Hirsch?

STATEMENT OF DANIEL O. HIRSCH, CHAIR, WORKING GROUP ON SPACE NUCLEAR POWER, FEDERATION OF AMERICAN SCIENTISTS

Mr. HIRSCH. Thank you very much. My name is Daniel Hirsch. I am a member of the National Council of the Federation of American Scientists and chair its Working Group on Space Nuclear Power.

I have just returned from a week in the Soviet Union for meetings with Soviet scientists on the issue of Cosmos 1900, as well as possible bans or moratoria on future deployment, and have brought back the statement by Academician Sagdeev that you have read part of. Additionally, through Academician Sagdeev we met with the head of Glavkosmos and also the person most responsible in the Soviet Foreign Ministry for this issue.

I bring back some information about Cosmos 1900 and also about the potential Soviet response, were there indeed some interest on the part of the U.S. government to discuss the problem of space nuclear power more generally. Before I discuss the information that I learned in my visit, I would like to put it in some context.

To do that I would like to make one personal observation, which is that during our visit to the Soviet Union we urged the Soviet officials to be more open regarding details of Cosmos 1900 and their space nuclear power program generally, to not repeat the problems that occurred during the first few days of Chernobyl and the problems that occurred when Cosmos 954 returned.

There seems to indeed have been some movement in that regard, as evidenced by what we were told and the commitment made to release more details before the reentry of Cosmos 1900.

I should just say as a personal comment after listening to the presentation by the previous panel of U.S. government officials that a little bit more openness by our government about our space nuclear power program would also be useful. I would like in particular, as I put this in context, to refer to several of the points they made.

I am going to move for a moment, if I may, to the transparency projector.

Well, there seems to have been a failure in the power source, and I may have to take some "backup" measures. I will try to speak without the visual aids.

We were told that there is an unblemished safety record in the U.S. space nuclear power program, and yet an important point to know is that the failure rate for U.S.-based nuclear power is approximately the same as for that of the Soviets.

About 15 percent of our space nuclear power missions have suffered one form of failure or another. That is about the same percentage as for the Soviets.

Now, some may assert that our failures were less severe. The reality is that the estimates that have been performed by government contractors for DOE indicate that the 1964 U.S. failure, which was the first nuclear power accident in space, was about 50 times more consequential than either of the two Soviet Cosmos reactors that have come down to date.

Whereas the Soviets do indeed rely primarily on reactors, to date we have relied primarily on plutonium sources. As Mr. Aftergood indicated, those you cannot launch cold. They are dangerous on their way up to orbit or if they fail to achieve orbit. In 1964, the SNAP-9A burned up over the Indian Ocean, releasing 17,000 curies of plutonium-238, tripling the world environmental burden of that isotope.

We have had several other incidents as well. The key point is that, although much of our technology in other areas may surpass that of the Soviets, with regard to space accidents we have had our own share of troubles. Similarly, with regard to nuclear power accidents, we have also had our own troubles. And in the area of space nuclear power, the failure rate is approximately the same.

It was also stated that we do not behave like the Soviets, that we put our reactors into "nuclear-safe" orbits. Well, the point, of course, is that we have only had one reactor in space, which failed after 43 days.

That one happens to be in a high orbit. But as Mr. Aftergood has indicated, the Department of Energy and SDIO have recently abandoned the safe orbit standard.

The CHAIRMAN. Well, give me an estimate on the safety of reactors which are put in high orbit and are encapsulated for falling to the earth.

Mr. HIRSCH. We did some detailed work on that during our technical meetings in Moscow last week, and have concluded that the so-called nuclear-safe orbit is not nuclear-safe. And there are a number of reasons for that.

The "nuclear-safe" orbit is the region around earth that is most populated by space debris—many thousands of items of space debris currently—and the amount is increasing exponentially with time.

The probability, over the many tens or hundreds of years that that radioactive waste must be kept from the earth environment, that there will be a collision between one of those reactor cores and some space debris, fragmenting the reactor and causing a substantial portion of those radioactive fragments to return to earth, is unacceptably high.

Additionally, one of the primary kinds of accidents that one worries about with space reactors is a power excursion. That is where the power runs exponentially out of control and the reactor blows itself apart.

If the power source had worked here I would be able to show you some photographs of a space reactor that the United States blew apart in its test program in the 1960s by simply rotating the control drums so that the power went up too high.

If there were such an accident, the reactor would be blown to smithereens. And again you would have fragments raining down upon the earth.

You should realize also that in addition to some of those fragments simply being directed out of orbit toward the earth, the surface area increases dramatically from something that is a single item to many, many fragments. Drag therefore increases and you have much earlier reentry than the supposed several hundred years that is planned.

Lastly, it should be remembered that both the Soviets' and the U.S.'s only real plans for space nuclear power in orbit are for military purposes. As indicated earlier, we have justified Soviet RORSATs as a target for our ASATs.

The Soviets, of course, have indicated that were we to put up SDI-type systems, one of their options would be to target our systems. The problem is that you are using ASATs to target reactors. There is no better way to fragment a nuclear reactor than to aim a weapon at it in a military fashion.

So in a real sense an ASAT would be bringing down reactors back to the earth from which those ASATs had been launched.

For those reasons, and a number of others, the so-called nuclear-safe orbit simply does not provide the safety necessary.

The same thing can be said of the "SIREN" idea, that one can go up and retrieve these very hot devices, were they in trouble. The idea is to put a hook onto the reactor and attach a grappling hook from another satellite and throw it into a higher orbit.

Well, there might be a hook you can grab onto. But if the reactor has been damaged by space debris, had a power excursion, or been hit by an ASAT, you might grab the hook but there would be nothing else except fragments, a cloud of fragments.

One other point is that, were there to be an incident involving fragmentation of a space reactor, even in a "nuclear-safe" orbit, those fragments could well end up creating a chain reaction of fragmentation of other reactors in similar orbits.

One of our Soviet colleagues referred to this as kind of like a car race, where there is one accident and that accident creates a chain of others. This is because you would create a cloud of fragments which then become more space debris capable of hitting more of these reactors.

Recall that this is basically a disposal plan for high-level nuclear waste, and that we must do that safely for hundreds of years. In these orbits they might have a million orbits during that period.

The probability that in those million orbits there would be some form of collision seems particularly troublesome.

Let me make a couple of other points, if I may, about the openness question. We have been told by the Administration that SDI will be non-nuclear, and yet about 10 percent of the SDI budget goes to either nuclear bomb-pulsed systems or nuclear reactors.

Senator Bumpers. Nuclear what?

Mr. Hirsch. Nuclear explosive-pulsed systems or nuclear reactor powered systems. There are five nuclear bomb-pulsed systems that the SDIO program has spent money on to date, and five reactor systems, together totalling approximately 10 percent of the budget.

Now, I understand that there is substantial pressure to find some cost-savings in SDI. It would appear to me that the advocates of SDI would be well-advised to cut the nuclear component because it is indeed the political underbelly of SDI, which was recognized by the President in making the pledges it will be non-nuclear.

I do not believe that the public is going to accept a system that involves dozens, perhaps scores of reactors floating overhead, with a high probability of some of those returning to earth.

If the advocates wish SDI to survive, and the public to continue to think of it as a brightly-colored crayon rainbow, safe above them, the SDI proponents are going to have trouble explaining the program if in fact it involves a hundred small Chernobyls, not safely above us but with the capability of falling back.

These reactors might be closer to us as they go overhead than many of the terrestrial reactors that we live nearby. Unlike terrestrial reactors, they can get much closer when they return to earth.

As for those who are critical of SDI, I believe that a ban that would preserve civilian missions while restraining military use and I will explain how that can be done—provides a very viable way of reinvigorating the ABM Treaty.

We have had difficulties finding strong verification mechanisms for assuring that the ABM Treaty is complied with.

The easiest handle on controlling the militarization of space is to control the power source, because you do not need big power sources in orbit for anything but military functions. And therefore you need big reactors.

A reactor is an extraordinary device. Lots of power over long periods of time——

The CHAIRMAN. How about that factory in space that he was talking about?

Mr. HIRSCH. That again is way beyond the time period for the proposed moratoriums that we have been thinking about.

What we have suggested is that in the near-term, in terms of what might be done into the early part of the next century, there is no scientific mission that would be affected by our proposed ban.

At that point, when it begins to look like there might be civilian uses, at that point you have a review to see whether you want to extend this further. But our proposal would restrain the military uses and keep free the legitimate scientific functions.

My point about verification is that a reactor gives off very strong signals. I wish I was able to show you what the U.S. SP–100 looks like. A very small reactor, but a huge radiator. One design for the even larger multi-megawatt reactor would have a radiator the size of football fields, giving off large amounts of infrared radiation easily trackable by earth.

Reactors also give off copious amounts of gamma radiation and neutrons, all making them easy to verify. It is a very powerful way of reinvigorating the ABM Treaty and being able to verify it. So I believe that advocates as well as opponents of SDI would be well-served to support this kind of moratorium.

I would also argue that those who are concerned about civilian space missions should realize that tying the future of civilian space nuclear power to SDI is the best way of destroying the potential for genuine scientific uses.

Right now there is pressure to design a reactor for military use. That design would be quite different if you were trying primarily to design something that was mission-driven for civilian scientific purposes.

Right now almost all of the direction of the SP–100 and related programs is coming from SDIO. And if you look at the General Accounting Office report that was done recently on the challenges facing space reactor power systems development, there was a warning in there that what caused the demise of the space reactor program of the United States in the early 1970s, was the lack of a defined mission, and that problem threatens the space nuclear power program once again.

I would argue that tying the future of genuine civil needs for space nuclear power that are somewhat off in the future to this military purpose is the best way to bring down the potential for legitimate scientific uses.

One indicator of that is that the GAO report estimates that it will cost $1 billion simply to test the first SP-100 in space. The trade press has been quietly saying they think it is quite unlikely that this program is going to go forward when Congress realizes that price tag.

Now, in an era of budget deficits, an era in which SDIO——

The CHAIRMAN. To test the first SP-100?

Mr. HIRSCH. Flight-test, the first flight-test will cost in excess of $1 billion.

So the reality is that it is throwing money into a program that is not going to go forward and which will bring down the genuine reasons to do somewhat more thoughtful mission-driven work.

The CHAIRMAN. You mean the test itself or the expenditures between here and getting it up there?

Mr. HIRSCH. No, the expenditures for putting together the package and launching that package and doing all the rest of that test. There are other expenditures unrelated to that test that are also in the hundreds of millions of dollars.

So this is an extraordinarily expensive program that I believe will bring down what would be a legitimate, a thoughtful program, if we put some direction in it.

Our proposed moratorium would simply extend somewhat the period of development of space nuclear power for legitimate purposes, provide some rationality to the program, and preserve the ABM Treaty. I think that is all very useful.

Let me make another point, if I may, and then tell you a bit of what I learned on my visit to the Soviet Union. It is true that Soviet programs and the American plans are quite different. But those differences are not all or even largely in the area of increased safety in the United States side.

The SP-100 first generation reactor would have more than 100 times the long-lived radioactivity of the Cosmos 1900 that is falling back. The second generation would have in excess of 1,000, and the multi-megawatt reactor many thousands of times the equivalent long-lived fission product inventory.

In other words, it would take hundreds to thousands of RORSAT-type accidents to have the equivalent consequences of one accident involving these very large reactors that the United States is planning to build.

The CHAIRMAN. Not the SP-100, you mean.

Mr. HIRSCH. SP-100 would be 100 to 1,000 times more dangerous if an accident were to occur to it than the Cosmos 1900 that is expected down in the next couple of months.

The CHAIRMAN. And that is only 100 kilowatts?

Senator BUMPERS. We were talking about the weight of the core.

Mr. HIRSCH. No, the amount of uranium is not the indicator. It is the power and the operating time.

The power of the RORSAT is on the order of 100 kilowatts thermal, the power of the SP-100 first generation is 2.3 megawatts thermal. That is 23 times more power. The SP-100 is intended to operate for seven years. The RORSATs operate for a few months.

Those two factors make the first generation SP-100 over 100 times more dangerous, if there were an accident, in terms of a long-lived fission product release.

Senator BUMPERS. Mr. Chairman, I do not understand why you say the weight of the uranium, for example, is not the test, it is the kilowatts.

Mr. HIRSCH. The question is how much of that uranium is fissioned over time. One can generate a certain amount of power out of a reactor of 50 kilograms, but one can also generate larger amounts. One can also run it for a shorter or longer time. The risk is a function of how much power and how much operating time. Now, there is, of course, a point at which one runs out of fuel.

Remember again, however, that the SP-100 would have at least on the order of four times the highly-enriched uranium of the RORSAT. And your earlier point on this matter, by the way, Senator Bumpers, was extraordinarily on target. In addition to the radiological hazard, there is a substantial safeguards hazard, because we are talking about 190 kilograms of 97 percent enriched uranium. In some research reactors we still find 90 percent, 93 percent enriched fuel and are amazed that that weapons grade stuff is still used and available for theft. But to use 97 percent enriched uranium, and many, many bombs worth of it—that is a substantial risk.

I have here a Los Alamos study that was done on this issue. You have heard today about the alleged safety of intact reentry. Los Alamos tried to figure out what to do about this reentry problem because there is this difficulty: if it comes down intact it may come down with many bombs worth of material all in one place.

There are countries that are spending millions of dollars to learn enrichment or reprocessing; intact reentry could put in their possession, without any of that fancy technology, many bombs worth. And I must take issue with the statement that——

Senator BUMPERS. It was Col. Hess. I'm told he might be contradicted.

Mr. HIRSCH. Just assume that he is contradicted. Los Alamos was concerned enough about this that what they did is they recommended a compromise between burnup in the atmosphere, as the Soviets do, which disperses the radioactivity, and intact reentry as we have now apparently decided, which gives the possibility of obtaining large amounts of this material.

Their compromise is that the reactor should be designed to break up into sub 25-kilogram parcels, because the International Atomic Energy Agency has a rule that anything more than 25 kilograms is considered strategically significant and you should not let it out of your control without very tight safeguards.

So to try to remain in some quasi-compliance with that guideline, they propose breaking it up into 24-kilogram components, which is still enough for several weapons. But you see the problem, you cannot win.

Senator BUMPERS. How many kilograms are required to make a weapon?

Mr. HIRSCH. Well, that obviously is a function of the skill of the designer.

The Nuclear Regulatory Commission's formula quantity is five kilograms of highly-enriched uranium. Calculations we have done indicate that a skilled designer could do it with less. If you want a lightweight weapon——

Senator BUMPERS. Ten pounds is a fair figure, is it not?

Mr. HIRSCH. If you were designing your weapon to minimize the amount of highly enriched uranium, yes. So this would be many bombs worth.

Senator BUMPERS. Well, one final question on that point. How difficult would it be if somebody lays their hands on 190 kilograms of intact of unexpended, fairly still——

Mr. HIRSCH. It could be fresh. Remember that this is not necessarily irradiated—it can fall back prior to achieving orbit, as several have.

Senator BUMPERS. So how difficult would it be then to convert that into a nuclear weapon?

Mr. HIRSCH. If you had 190 kilograms, you could do a gun-type device, which is the simplest. The U.S. did not even have to test our first gun-type device, as you know the one dropped on Hiroshima. We knew it would work without testing it.

I would say that this is not the central question. I should say that this is really a secondary or tertiary issue. But it remains a significant proliferation problem, and I do not believe it has been addressed.

They cannot address it. If the reactor comes down in one chunk, you can get a lot of bomb material. If it comes down dispersed, you spread the radioactivity. There is no solution to the problem.

There is no nuclear-safe orbit, there is no safe reentry mode, and there is no way of retrieving these things, if they get into trouble.

Senator BUMPERS. Well, why would Col. Hess say no, you cannot make a weapons grade——

Mr. HIRSCH. He did not. He said it would take some chemical reprocessing to separate out the nitrogen from the uranium. But that is a trivial matter for a country interested in obtaining a nuclear weapon.

Okay, let me tell you a little bit of what I learned in the Soviet Union. I know I am taking a great deal of your time.

We met with the person most responsible in the Foreign Ministry for this issue. We were informed the following about Cosmos 1900, and you have heard some of it in summary already.

There is a system designed to boost the reactor into higher orbit, but that requires radio command from the ground. As they have lost radio contact, they cannot give the command.

They have three backup systems, or automatic switches on board, which are supposed to automatically boost the reactor into a higher orbit, if any of these three conditions are met.

The man with whom we met said quite charmingly "that the problem with the blasted thing is that it is working too well." None of these conditions have occurred. One condition is that the reactor becomes depressurized. This is what they believe contributed to the Cosmos 954 accident. "Unfortunately," the reactor is working fine.

Second is that there is loss of attitude control. The problem is the reactor is still operating, an important piece of news, although he did not know if at full power. The reactor is still on. So there are more fission products and no time for decay. Therefore there is still plenty of power and still attitude control.

The third condition is if there is a break in the electrical system of the satellite. The problem again is that it is working too well. Now, something may still go wrong with the satellite and it may still be able to be boosted into higher orbit.

But if not, it will reenter. And at that point when it gets down to about 120 kilometers it will start, through friction with the atmosphere, heating up. At about 100 kilometers they say the heat will trigger a temperature switch. The temperature will rise to a high enough level that a switch will be triggered and the core will be ejected. The fuel will burn up in the atmosphere.

They said there would be no risk, because it would burn up. We reminded them that these statements have little credibility among knowledgeable people in the West because radioactivity, of course, when it burns up is still radioactive.

Fission products, or plutonium or any of these radioactive materials, when they become an oxide, are merely radioactive material in oxide form. It is simply dispersed and can cause cancer deaths. Our Soviet colleagues, in fact, have coined a new unit of risk called the Chernobyl, which is rather intriguing that they would use that as their unit or risk. Much of our technical work over the last week was trying to provide qualitative fractions or multiples of Chernobyls for RORSAT, for SP–100, generations one and two, and for the multi-megawatt reactor. So we tried to disabuse the Foreign Ministry of the idea that the fuel burning up ceases to present public risks.

They believe that it will come down September to mid-October. Their best guess is mid-October. In a rather cute comment, they said Cosmos 1900 is a royal headache for them. I believe it is, and I told them we would try to continue to make it more of a headache.

I indicated that there was some interest in the Congress in suggesting that our government initiate some discussions with their government about the future of space nuclear power. And I asked, what would be their response were there to be such an inquiry. Academician Sagdeev had already been to the Foreign Ministry several times to press his case for a ban on nuclear power in orbit.

By the way, this is an extraordinary change for the Soviet Union. Here is a senior person in the Soviet Union holding a press conference in Washington, DC on May 13 criticizing his government for putting up nuclear reactors and saying they should stop. He is thus way ahead of his government. It was made clear that Sagdeev did not speak for the government but that they listened seriously to his advice.

I asked what would happen if a ban or moratorium along the lines that Sagdeev and our Federation group have proposed, or some other alternatives, were proposed for discussion by the U.S. Government.

And I was told explicitly that were there any such initiation of a suggestion of discussion on these matters that it would be taken most seriously by the Soviet Government.

I believe that there is a clear indication that were we to initiate such discussions that that initiative would be taken quite seriously. And I think some prodding of our Government along that line might be in order.

So I have a lot of other things I should say, but let me just conclude——

The CHAIRMAN. Well, why do we not get to questions?

Mr. HIRSCH. Let me conclude with one comment. We are at an important threshold in the history of space nuclear power.

To date the risks associated with space nuclear power, both the military risks and the environmental, have not been insubstantial but nonetheless were relatively modest. We are now posed before the doorway of a situation that could involve vastly increased those risks.

The plutonium power sources that SDIO is looking to create could contain 50 kilograms of plutonium-238, the equivalent in curies, as Mr. Aftergood has pointed out, of two and a half times all the plutonium isotopes released in atmospheric fallout during the testing program. These are very large sources, just the plutonium sources. The reactors, as I have indicated, are huge in terms of their potential hazard were there an accident.

The SP–100 flight test is still set for 1996, if SDIO has its way. We have not yet started to put these very large sources into space. The program has not fully distorted the genuine scientific mission. This is the time for us to rethink the program and at the same time get the Soviets to rethink their plans, and to create a situation where for a reasonable period of time nobody puts these nuclear sources into places where they can cause harm.

We can review that in the future. But in the near term, where there are no civilian uses in orbit seriously planned, only military, the idea of putting these reactors and other power sources into situations where they can come back and cause untold harm on Earth simply needs to be reassessed. And this is the time to do it.

[The prepared statement of Mr. Hirsch follows:]

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STATEMENT OF
DANIEL O. HIRSCH
CHAIR
WORKING GROUP ON SPACE NUCLEAR POWER
FEDERATION OF AMERICAN SCIENTISTS

BEFORE THE
COMMITTEE ON ENERGY AND NATURAL RESOURCES
UNITED STATES SENATE

September 13, 1988
Washington, D.C.

Mr. Chairman and Members of the Committee on Energy and Natural Resources, I appreciate your invitation to appear before you today on behalf of the Federation of American Scientists (FAS) to discuss our proposal, issued jointly with a group of senior Soviet scientists, for a ban on nuclear power in earth orbit. This proposal has been made more timely by the imminent reentry of Cosmos 1900 and work within the United States to develop reactors for Star Wars purposes that would be very much more powerful, and thus more dangerous, than the Soviet space reactor whose failure has stimulated this hearing.

My name is Daniel Hirsch. I am a member of the National Council of the Federation of American Scientists and Chair the FAS Working Group on Space Nuclear Power. I have just returned from a week of meetings in the Soviet Union on Cosmos 1900 and the problems associated with nuclear power in space. I will be reporting on the results of those meetings, among other matters, in this testimony. Professionally, I am Director of the Stevenson Program on Nuclear Policy at the University of California, Santa Cruz, although it should be made clear that the views expressed here do not necessarily represent those of the Program on Nuclear Policy nor the University of California.

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The Problem of Space Nuclear Power

The troubles currently being experienced by the Soviet nuclear-powered surveillance satellite, Cosmos 1900, graphically demonstrate the risks associated with nuclear power in earth orbit. The high failure rate of such nuclear devices, both Soviet and American, and plans for very much larger systems in the future, suggest that this would be an appropriate moment to pause and reassess their use.

Our FAS group was in Moscow for a week-long working meeting organized by FAS and the Committee of Soviet Scientists, examining technical questions associated with space nuclear power, such as potential consequences of accidents, methods of verification of a ban, and problems associated with alternative responses such as so-called "nuclear safe orbits" and concepts for possible retrieval of space reactors in trouble. We made substantial progress on each of these questions, with consensus achieved between both our American and Soviet participants.

While in Moscow we met several times with the outgoing director of the Soviet Space Research Institute; I have carried back with me a statement by him for this Committee. We also met with the head of Glavkosmos, the Soviet civilian space agency, and with the official in the Soviet Foreign Ministry most responsible for issues associated with space nuclear power. I bring back information about Cosmos 1900 as well as indications about the likely Soviet response were the U.S. to attempt to initiate discussions to address the problems associated with space nuclear power.

Before summarizing this information, some context regarding the space nuclear power issue might be helpful.

The FAS-CSS Proposal

On May 13 of this year, the Federation of American Scientists and the Committee of Soviet Scientists Against the Nuclear Threat (CSS) held a press conference at the National Press Club to announce our joint proposal for a ban on nuclear power in earth orbit. The proposal had been in preparation for months as part of a five-year project of studies involving the two groups. Coincidentally, a few hours after we called the press conference, wire services ran a story that a Soviet satellite with a nuclear reactor on board was in trouble, providing an unexpected underscoring of the points we were attempting to make about the risks involved.

Our proposal was relatively simple: we would ban nuclear power in orbit while preserving the option of its use for civilian scientific purposes such as deep space missions. This would serve the dual purpose of protecting the earth environment from radioactive contamination in case of accident and providing a restraint on the militarization of space.

We believe Cosmos 1900 represents a warning: rethink the use of nuclear power in space before there is a quantum leap in risk. In what follows I describe briefly past and current U.S. and Soviet space nuclear power programs, as well as plans underway for very much more powerful and more dangerous reactors for the future.

The Soviet Program

The Soviets use space nuclear power primarily to run their Radar Ocean Reconnaissance Satellites (RORSATs). These are designed to track and target U.S. naval groups and as such are viewed here as offensive and provocative. RORSATs are reactor-powered because they operate at low altitude where solar collectors would provide too much atmospheric drag. The reactor core is designed to be boosted into higher orbit at the end of their useful life to prevent reentry while still radioactively dangerous. It is precisely the failure of that boosting system that led to the accidents involving Cosmos 954 and 1402 and appears to be the problem faced now by Cosmos 1900.

Two space reactor designs are reported in the Western open literature: the Romashka and the Topaz. The former, the earlier of the two, is said to have produced on the order of .5 kilowatts of electricity using uranium carbide fuel in graphite. Topaz is said in the West to be 100 kilowatts (thermal), utilizing 50 kilograms of 93% enriched fuel in the form of uranium oxide, although while in Moscow we received some indications that the power level is up to 220 kw_{th}, utilizing only 12 kg of fuel, enriched to 90%.

The U.S. Program

To date, the U.S. has tended to rely much more on isotope power sources using plutonium-238 than on reactors, although that may now be changing. We have launched 22 spacecraft with plutonium sources and one with a reactor (which failed after 43 days). We have had our share of accidents, with perhaps the worst accident in the history of space nuclear power being the burnup of a U.S. plutonium-powered navigational satellite over the Indian ocean in 1964, tripling the amount of plutonium-238 in the world environment.

Table I

HISTORY OF SPACE NUCLEAR POWER

	US	USSR
1st radioisotope generator launched	1961	1965
1st nuclear reactor launched	1965	1968
1st space nuclear power accident	1964	1969

Our early space reactor program, active in the 1950s and 1960s, was terminated in the 1970s for lack of a mission. This is a problem being repeated in the U.S. space reactor program today, with the General Accounting Office warning that the new program may go the same way as the old one due to lack of a demonstrated need. Space nuclear power continues to appear to be a technology in search of a mission.

To the extent that there is a mission for U.S. space nuclear power, it is SDI, a controversial program that may actually set back the use of nuclear power for legitimate deep space scientific purposes.

SDI and U.S. Space Nuclear Power Programs

Despite Presidential pledges that SDI would be "non-nuclear," approximately 10% of the SDI budget goes for the development of nuclear-bomb-pulsed or nuclear-powered systems. SDIO has worked on five bomb-pulsed concepts and five that are reactor-powered. The latter are:

- SP-100--a liquid-metal-cooled, fast reactor, fueled with weapons-grade uranium, designed to operate at about 2.3 megawatts (thermal), providing 100 kilowatts of electricity for 7 years. Future designs are supposed to increase the reactor power to about ten times the original design.
- Multi-Megawatt Reactor--planned to provide tens of megawatts of electricity for up to a year for alert mode for battle stations or hundreds of megawatts for hundreds of seconds for burst mode for directed energy and related weapons. This system is much less far along than SP-100, but would doubtless be very large; one design concept involves radiators the size of football fields.

- **Dynamic Isotope Power System (DIPS)**--a system providing up to 10 kilowatts of electricity from the heat generated by the decay of several dozen kilograms of plutonium-238, an extraordinarily large amount from a radiological protection standpoint, if released in an accident. SDIO is said to be having second thoughts about using DIPS for its Boost Surveillance and Tracking System (BSTS) because of the extreme cost of producing such a large amount of the rare material.
- **FALCON (Fission Activated Laser Concepts)**--a reactor concept involving direct pumping of a laser weapon by fission fragments from an operating reactor.
- **Centaurus**--a second reactor project involving direct pumping by a nuclear reactor of a directed energy weapon. Full cost of the program, to time of completion, is estimated as $2.5 billion.

General Abrahamson, DOE, the American Physical Society, and the Congress's Office of Technology Assessment have all indicated that nuclear power may be essential for at least a second phase of SDI. At other times SDI advocates are coy about the question, saying nuclear power may not be needed at all. To the extent nuclear power is not needed for SDI, that it will indeed be non-nuclear, SDI advocates should have no objection to our proposed ban. To the extent they do object, they should have to explain to the American public how their "non-nuclear" system contemplates use of perhaps a hundred high-powered space nuclear reactors. They should particularly be required to do so in light of the high accident rate of such systems in the past and the public concern associated with the very much less powerful, and thus less dangerous, Soviet reactors aboard their ill-fated RORSATs. An **accident involving just one SDI reactor could have the radiological consequences equivalent to many hundreds of falling RORSATs.** To the extent one is concerned about Cosmos 1900, one should be hundreds of times more concerned about these high powered U.S. space reactors for Star Wars.

Table II

Risk Comparison, US Star Wars Reactors and Soviet Topaz Reactor

	Topaz	SP-100 Gen.1	SP-100 Gen.2	Multi-Megawatt
weapons-grade uranium (kg)	12	190	>>200	>>200
power (MW_{th})	<.22	2.3	~23	~230-700
operating time (yrs.)	~.5	7	7	1
relative long-lived fission product inventory	1	150	1500	2000-6500

U.S. Star Wars reactors would be ten to thousands of times more powerful than the Soviet Topaz, operating as much as 15 times as long; these two factors together would mean long-lived radioactive inventories available for release to the environment in case of accident hundreds to thousands of times larger.

Additionally, they would have at least 15 times the weapons-grade uranium aboard as fuel, many bombs' worth, posing a safeguards/proliferation problem as well.

New Information About Cosmos 1900

In a meeting at the Soviet Foreign Ministry with the official with primary responsibility for the issue, we were provided the following information about Cosmos 1900 (I have tried to preserve the language used as much as possible):

> The Soviets have lost communications with the satellite, so there is no way to give the command to boost to a higher orbit. Furthermore, the backup systems to automatically boost to such an orbit have failed to operate because, ironically, they were designed to be triggered by one of several potential failures in the satellite, none of which, "unfortunately," have occurred. The problem is thus, we were told, that the reactor and satellite are working "too well."
>
> Even before Cosmos 954 (the Soviet reactor which reentered over Canada in 1978), Soviet reactor-powered satellites were

equipped with a system to boost the energy part of the device up to about 800-900 km orbit in order to delay reentry. Cosmos 954 was equipped with such a system, but it didn´t work.

After Cosmos 954, there were extensive discussions at the UN about space nuclear power, leading to recommendations for two systems--one to boost the core to a higher orbit at the end of the satellite´s useful life, the second to separate the active part of the reactor from the rest of the satellite should the first system fail and the reactor begin to reenter. This latter feature, which was to be activated when the satellite comes in contact with the dense layers of the atmosphere, was designed to cause the fuel to "burn up" in the atmosphere rather than return in fragments as happened in the Canadian case. [As shall be discussed later, this does not mean that the long-lived radioactivity disappears; it is simply dispersed more globally.]

As for the first system, to boost the core to a higher orbit, this system was to be activated from earth. Loss of radio communication with the satellite has prevented such activation. There are, however, three automatic switches on board the spacecraft which can, even in the absence of a radio command from earth, cause the core to be boosted. The three situations which should cause automatic activation of the boosting mechanism are:

> (1) Destabilization of the satellite (i.e., loss of attitude control.) Unfortunately, we were told, the stabilization system is automatic and working perfectly. The reactor is still on (the official with whom we spoke did not know, however, if still at full power), and thus there is a reserve of power for attitude control. The satellite thus "doesn´t give itself a chance to switch on the safety system."
>
> (2) Depressurization of the reactor. The accident with Cosmos 954 in the late 1970s is believed to have been associated with a rapid depressurization of the reactor, perhaps caused by collision with space debris. Cosmos 1900 is designed to automatically boost if such depressurization occurs, but, again, "unfortunately" everything is working fine.
>
> (3) Disruption in the "energy situation," i.e. failure in the electrical system. Again, "unfortunately," this system is also working perfectly, so the automatic boosting mechanism can´t be activated.

In sum, they can´t command Cosmos 1900, it is losing altitude, but otherwise "working too well" to date to cause initiation of the automatic boosting backup systems. It is possible to boost, may still be boosted, but may not.

[We inquired about the first automatic system involving loss of attitude control, asking how the boosting mechanism could assure it would boost up to a higher orbit rather than down toward the earth if the satellite were tumbling. We were told that the allowance of attitude control loss was very small, a threshold of only a few degrees before boosting was automatically initiated.]

If all three conditions continue to remain undisturbed, the orbit will continue to decay and the reactor will begin to reentry the atmosphere. Cosmos 1900 is currently in excess of 200 km up. At less than 120 km, substantial friction with the air will begin, and at about 100 km, that friction will start a signal to eject the reactor core to facilitate its disintegration in the atmosphere as it reenters. Temperature is the signal; when temperature reaches a certain threshold, the core is ejected. There is no connection between the system to boost the core to a higher orbit and the ejection system for atmospheric burnup should the boosting system fail.

[It was asserted that, even should boosting continue to fail, there was no risk to the earth because the radioactive material would burn up in the atmosphere. We made clear that this was not technically correct because radioactive material did not cease to exist simply by dispersing it, that it would settle down to earth as radioactive fallout and could result in on the order of several hundred cancer deaths.]

There are "at least" one and a half months to go before reentry. They have revised their previous estimates; the new estimate is September-October. Their best guess is mid-October or later.

We asked for information about the reactor design, fission product inventory, power and operating history, all of which would be useful in assessing environmental risk and assisting in emergency response measures, should they be necessary. The official said he did not have that information. We stressed the importance of detailed information being released by the Soviet Union to avoid the problems experienced during the Cosmos 954 and the early days of the Chernobyl accident. We were assured that further information would be released before reentry and that the Soviet Union would meet its obligations under the IAEA Convention on Early Warning on Nuclear Accidents and the Convention on Assistance of the IAEA. We urged that this further release of information include the kind of technical detail we had outlined.

We were told that Cosmos 1900 is "a royal headache" for them.

Views About Bilateral Discussions on the Future of Space Nuclear Power

We were told that the issue of whether nuclear sources should be placed in orbit came to the fore after Chernobyl. In the wake of the problems with Cosmos 1900, they are assessing the issue again.

We urged the discontinuation of launches of nuclear RORSATs and consideration of a ban along the lines proposed by our FAS group and Academician Sagdeev and his colleagues at CSS. We indicated that there was interest in the Congress in urging the Administration to initiate discussions with his government about the problem of space nuclear power. We were told that "if there were an initiative by the U.S. government to in any way make outer space more safe, it will be very seriously considered" by the Soviet government. "If the U.S. government were to say to the U.S.S.R., ´Let us consider neither of us launching into outer space nuclear power, and such a matter were to be mutual, it would be very seriously considered by the Soviet side."

Policy Options

1. **Moratorium/Ban on Space Nuclear Power.** We believe that the best approach to the array of problems associated with space nuclear power is to ban its use in earth orbit and create a 15 year moratorium on reactor use for deep space missions. This would not interfere with RTG-powered deep space uses such as the U.S. Galileo and Ulysses probes, nor possible use of reactors for such civilian enterprises as a Moon base or a manned mission to Mars, neither of which is contemplated before 2005 at the earliest. Such a ban/moratorium would, however, protect the earth from the environmental risks associated with reentering orbital nuclear power sources and provide a useful restraint on the militarization of space.

Other policy options have been proposed. We have examined them in some depth and conclude that none satisfactorily address either the environmental nor the arms control problems associated with space nuclear power. The alternative approaches are briefly reviewed below.

2. **"Nuclear Safe Orbit."** Some have argued that requiring the placement of nuclear sources in orbits higher than about 800 km would resolve the environmental concerns, albeit greatly complicate arms control issues. Such orbits, it is argued, decay more slowly than the bulk of the long-lived fission products in the reactor fuel, delaying reentry sufficiently to reduce environmental risk to negligible levels. A more thorough examination of this proposal, however, indicates that it does not resolve even the environmental risk. Furthermore, it is noted that DOE has recently abandoned the

nuclear safe orbit restriction, and SDIO contemplates possible uses of nuclear sources in orbits below than 800 km threshold.

As to the environmental side, our Soviet and American groups have both concluded that "nuclear safe" orbits are not really nuclear safe. The region of such orbits is currently one of the most crowded with space debris of any region surrounding the earth, getting more crowded at an exponential rate. There are already thousands of pieces of space debris orbiting the earth, a number which is increasing rapidly. The probability of collision with space debris, particularly over the several hundred year period and million or so orbits that the nuclear waste must remain isolated from the earth´s environment, is unacceptably high. Already there have been a number of satellites damaged or destroyed by what is believed to have been space debris; in fact, one of the explanations for Cosmos 954´s troubles has been the possibility of impact with space debris. A small reduction in orbital velocity, or more importantly, breakup of the nuclear satellite, could send a shower of radioactive fragments toward the earth. Furthermore, fragmentation of the device by such hypervelocity collision would greatly increase its surface area and thus drag, bringing down the fragments far quicker than the assumed 300 years for the smaller cross-section undamaged satellite. Additionally, breakup of the satellite would create a large cloud of fragments dispersed along the orbit, potentially impacting other reactors, creating a chain reaction of fragmentation and deorbit of these reactors. One of the Soviet scientists at our meeting likened this to a car race where one collision initiates a number of others. The likelihood that all these reactors can remain in "nuclear safe orbits" for hundreds of years without collisions with space debris and resulting deorbit of radioactive fragments is not reassuring.

Additionally, it should be recalled that one of the primary accidents to be concerned with regarding space reactors is that of destructive power excursions or criticality accidents of the sort that blew the Chernobyl reactor apart. The U.S. intentionally detonated several space reactors in tests in Idaho by inducing such rapid increases in power (by rapid rotation of control drums, sending power out of control). The reactors were blown apart and the fuel fragmented. Space reactors are especially vulnerable to such accidents, due to the highly enriched uranium they use and the large amount of "excess reactivity" that must be built into them to compensate for the inability to be refueled during their long expected lifetime. A space reactor that explodes in a power excursion would have a substantial amount of its radioactive fragments reenter the earth environment, even if originally based in a "nuclear safe" orbit.

Lastly, it should be kept in mind that the only real contemplated use of reactors in earth orbit is for military uses the other side views as provocative--the targetting of our navy by the Soviets and the powering of SDI space battle weapons by the U.S. Both sides have indicated consideration of using ASATs to shoot down the other side´s space-based military assets. In this case, however, they are nuclear powered. A reactor destroyed by an effective ASAT will be broken into a cloud of radioactive fragments, raining down upon the earth. ASAT is thus a way of shooting down small Chernobyls floating above, bringing them back down to earth with their dangerous fission products. When we consider targeting a Soviet RORSAT, we are aiming at a nuclear reactor above us; when the Soviets consider shooting down SDI battle stations, they would be targetting much larger reactors above them.

Given mounting space debris, the potential for explosive reactor accidents, and targeting by ASATs, there is no such thing as a "nuclear safe" orbit.

3. SIREN--Shortly after we proposed our ban on space nuclear power, SDIO indicated it had underway a "SIREN" exploratory program--to consider possible "concepts" for retrieval of space reactors in trouble. The concept is extremely vague, sounding more like a political solution to the political problem posed by concern over space nuclear power than a workable technical solution. A reactor, particularly one in trouble, is very radioactive, making approach quite difficult. Carrying adequate shielding is very hard, given the mass involved. Given the launch troubles we have had, and other failures in the space program, it is hard to imagine a reliable way of retrieving nuclear reactors that are soon to return to earth.

But most importantly, all of the problems associated with "nuclear safe" orbits apply equally to SIREN. Even were one to have a spacecraft that could reliably approach a radioactive reactor in space, hook onto it and take it to a higher orbit, there must be an intact reactor to hook onto. If the accident that has disabled the reactor is a power excursion or collision with space debris or a meteor, or if it has been intentionally destroyed by ASAT attack because it is a military target, no SIREN, no matter how good, can put the reactor together again. Its radioactive fragments will come back to haunt us.

Conclusion

Cosmos 1900 demonstrates some of the risks associated with the use of nuclear power in orbit. The policy questions raised, however, are not limited to Soviet reactors. In fact, the U.S. is developing space nuclear power supplies for Star Wars uses which will dwarf all systems built to date.

Now is the time, before that threshold is crossed, to ban nuclear power in orbit. Such a ban would be readily verifiable because of the strong infrared, gamma, and neutron radiation emitted. This action would provide protection for the earth from accidents involving space nuclear power and be a useful restraint on the weaponization of space.

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U.S.-SOVIET SCIENTIFIC COLLABORATION CONCLUDES THAT A BAN ON NUCLEAR POWER IN EARTH ORBIT IS FEASIBLE AND DESIRABLE FROM BOTH A MILITARY AND ENVIRONMENTAL POINT OF VIEW

A JOINT PROPOSAL TO BAN NUCLEAR POWER IN EARTH ORBIT

The proposal which we put forward on behalf of our two organizations (after two joint workshops) to ban nuclear power in earth orbit grows out of our efforts to prevent both the radioactive contamination of the earth's surface and the extension of the arms race into space. In particular, this agreement would prevent the use of reactors in earth orbit by either side for any purpose — whether offensive or defensive, including the use of reactors to power surveillance satellites.

The use of nuclear power in space is still at an early stage but already there have been accidents which have caused worldwide concern.

An agreement to ban nuclear reactors from orbit would be a major barrier to any future arms race in space since nuclear reactors are compact sources of large quantities of power necessary for many military purposes. Meanwhile, as far as civilian activities are concerned, solar energy collectors and fuel cells will be a more convenient and safer source of energy in earth orbit for the forseeable future. Energy sources powered by quantities of radioisotopes below an agreed safe threshold could also be permitted for these purposes.

The ban on reactors in orbit would not prevent the use of nuclear power for deep space scientific or exploratory missions with associated very limited tests under agreed safeguards of such deep-space reactors in earth orbit.

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Verification of a ban on nuclear power in orbit would be relatively straight forward because an operating (or even recently operating) nuclear power source would emit large amounts of detectable infrared, gamma and neutron radiation.

We therefore call for an international agreement to ban nuclear power in orbit and our two organizations plan to continue to work on the technical aspects of this ban in the context of our 5-year Joint Verification Project.

Roald Sagdeev, Chairman Committee of Soviet Scientists Against the Nuclear Threat Scientists	Frank von Hippel, Chairman of the research arm of the Federation of American

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The Committee of Soviet Scientists Against the Nuclear Threat, established in 1983, is a non-governmental group of senior Soviet scientists formed for the purpose of scientific and technical analysis of the feasibility of disarmament agreements. Academician Roald Sagdeev, its current Chairman, is Director of the Space Research Institute of the Soviet Academy of Sciences.

The Federation of American Scientists, formed in 1945, is the oldest organization in the world devoted to nuclear disarmament, having been founded by some of the original Manhattan Project scientists for that purpose. It is sponsored by 45 Nobel Prize winners. Its project on "cooperative verification" is directed by Princeton Professor, Frank von Hippel, who serves also as Chairman of the research arm of the Federation of American Scientists (the FAS Fund).

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FAS STATEMENT ON THE JOINT PROPOSAL OF THE COMMITTEE OF SOVIET SCIENTISTS AND FAS FOR A BAN ON NUCLEAR POWER IN EARTH ORBIT

At present, the use of nuclear power in space is relatively limited, primarily the use by the Soviet Union of nuclear reactors to power RORSAT satellites. However, there are plans in the United States to develop and deploy large numbers of nuclear power sources for its Strategic Defense Initiative (SDI) program. Because of the unique environmental and strategic risks associated with nuclear power in earth orbit, and their past history of accidents, this appears to be a good time to consider a ban on such systems.

The history of space nuclear power to date has been a troubled one. About 10-20% of such missions, both Soviet and American, have suffered failures or accidents of one sort or another. For example, the 1964 U.S. SNAP-9A accident tripled the world environmental burden of plutonium-238 when the satellite carrying the plutonium power source failed to achieve orbit and burned up in the atmosphere, distributing its plutonium throughout the globe. And in 1978, the reentry of the Soviet Cosmos 954 space reactor spread thousands of pieces of radioactive debris over more than 100,000 square kilometers of northwest Canada. These and related incidents have raised considerable concern about continued use of such space nuclear power sources, let alone the possible deployment of large numbers of very much larger nuclear systems for SDI weapons purposes. The environmental consequences of reentry of such systems could be very serious.

In addition to the environmental and safety benefits of banning space nuclear power, there could be major strategic benefits as well. Prospects for the militarization of space, particularly those deployments contemplated for SDI, appear to rely heavily on large sources of power in space. Nuclear power systems, both reactors and advanced radioisotope power sources, are prime candidates for such uses. It may be possible to prevent or make more difficult the introduction of weaponry in space by controlling the power sources for such systems. This could help

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maintain the the ABM Treaty and keep the space environment benign.

It is therefore proposed that there be a ban on space nuclear power. We believe that this could be readily verified. After all, nuclear sources emit a number of signals (gamma, neutron, infrared) that are relatively easy to detect.

A ban on reactors for use in Earth orbit would not apply to reactors for use on deep space scientific missions, though any in-orbit testing of such reactors would be subject to severe restrictions.

Additionally, it may be necessary to negotiate a limit on power or radioactivity of radioisotope power sources for space use. If some radioisotope power source uses were permitted, they should be below a level capable of causing significant environmental impacts in case of launch accident or re-entry (e.g., the amount used in the SNAP-9A system, which disintegrated in 1964) and below a power level capable of having significant uses in the militarization of space. Such permitted sources might have to be jointly designed, or their design jointly approved, to assist in detection of and discrimination from non-approved sources.

Other than these two exceptions-- jointly approved reactor designs for deep space scientific missions and jointly approved designs for sub-threshold radioisotope sources-- space nuclear power would be banned. This would mean, among other things, that the USSR would be banned from continued use of nuclear power for its RORSATs and that US contemplated use of nuclear power for SDI would be likewise forbidden.

The CHAIRMAN. Mr. Hirsch, if there is a breakup of one of these reactors in space because of a collision, would that be the equivalent of the injection of the core into space for burnup?

Mr. HIRSCH. There are two different processes. It could fragment into some fairly large fragments, and some would be very small.

When some of those fragments hit the atmosphere they would burn up. So you would have the same effect.

The CHAIRMAN. Well, in the Cosmos 954 into Canada, it seems to me that that is a very great danger.

My first question to the Secretary was, if that happened over a populated area, would that not be dangerous? And he said, well, he would have to go back and check his calculations.

The fact of the matter is, that is the real danger we are worried about, is it not? I mean, the principal danger. Is not that danger many times more than that of just burning up completely in space?

Mr. HIRSCH. I am not sure. I believe that it is an issue of picking your poison.

Do you want to take that radioactivity, distribute it globally, so that many people receive small doses, and so the number of cancer deaths is distributed globally, or do you want it to come down in a more narrow location where the doses are higher and a smaller number of people get larger doses?

In radiation safety——

The CHAIRMAN. The former.

Mr. HIRSCH. Well, in radiation safety, it does not matter. The amount of cancer deaths are a function of the person-rems, the number of people exposed times the exposure. Large exposure for small numbers of people equals the same number of long-term casualties as smaller exposures to lots of people.

The CHAIRMAN. I would argue, and I have seen both the unclassified and the classified, and their conclusion is that the combined population dose risk of SNAP-9A, Cosmos 954, and Cosmos 1402 and Cosmos 1900 was estimated to be a very small percentage of the annual population dose due to natural background radiation. And I have seen those figures, if they are correct, I would suggest that that is correct.

One additional burnup in space I do not believe is a big danger. One satellite, I mean one core coming down and breaking up as it did in Canada and landing in Washington, DC would be a huge danger to a lot of people.

Mr. HIRSCH. Well, I agree that it would be a large danger. Let me just say two things.

One is that I am concerned that these consequence calculations are classified. I do not see any reason why the public cannot see what the estimates are for hazards from this program. I see no national security reason——

Senator BUMPERS. I think if I gave you a pad and pencil you could figure that out.

Mr. HIRSCH. It is political, not military.

The CHAIRMAN. Well, confidential, that is less than secret. I do not know why they are either.

Mr. HIRSCH. But Senator Johnston, I think one of the key points here is the policy point.

DOE reactors are unlicensed, they are unregulated, there is no public scrutiny, there is no chance for peer review to determine whether these assessments and assertions of safety are indeed correct.

We found the same situation within the DOE program right after Chernobyl. I was asked by a House Committee right after Chernobyl to take a look at the Hanford N-reactor. We were told, do not worry, we do not have any reactors that can have——

The CHAIRMAN. We will ask DOE to declassify that, because I think there is no reason for it to be——

Mr. HIRSCH. And I think this Committee should consider whether, if this program goes forward, whether those reactors should not come under public scrutiny and licensing as well.

The CHAIRMAN. But it seems to me the real danger here is a breakup, not the full burnup.

Now, burnup of hundreds of reactors or maybe tens of reactors over time, and certainly something the size of SP-100 would be a real risk I would think, whereas it would not worry me for Cosmos 1900 if it really does burn up, I mean that is so infinitessimal.

Mr. HIRSCH. Compared to SP-100 or multi-megawatt, it clearly is.

One other technical comment though. The comparison against overall global radiation background, which is indeed causing lots of cancers naturally, is something that is always done.

The question is not how many people, how many hundreds of thousands of cancers are naturally being produced. The question is whether hundreds, thousands or tens of thousands of additional cancer deaths by this activity is a legitimate function of our government or the Soviet government to be doing.

Particularly, as Mr. Aftergood points out, the people who will be dying in large measure will not be the people who had a chance to vote for you, or have any say in the policy.

The CHAIRMAN. Thank goodness. Well, to put in context though, Cosmos 1900 is not going to produce hundreds of thousands of——

Mr. HIRSCH. No. I believe we are talking qualitatively on the order of tens or hundreds of cancer deaths. When you get to SP-100, you start talking about potentially tens of thousands.

The CHAIRMAN. I mean, not that it is a good idea, but it seems to me that the real risk is that it does not eject the core into space and burn up. Not that it does.

Now, the question, the bigger question is, it seems to me, not should we have a treaty on nuclear power systems in space, but what are we going to do about the ABM Treaty?

If you have a real ABM Treaty that says you do not go to SDI, which the present ABM Treaty does prohibit effectively, then generally there is no need for the nuclear power systems, other than for deep space probes, and those can be well-regulated and be without substantial danger.

Mr. AFTERGOOD. Except of course the RORSATs are not prohibited under the ABM Treaty, but could be prohibited under an agreement specifically on space nuclear power.

Mr. HIRSCH. Which would reinforce an ASAT regime too.

The CHAIRMAN. Is it necessary to have those lower earth orbits? I will ask you the question that I asked the colonel.

Mr. AFTERGOOD. Necessary for the RORSATs?

The CHAIRMAN. Yes. Can you get the same information from 400 miles or 500 miles that you can at the lower orbits?

Mr. AFTERGOOD. Well, his answer was essentially correct. The closer you are the better shot you are going to get.

Whether they can compensate by increasing power level and increasing the radar aperture, whether that can compensate for the increased distance, it seems possible to me. But I do not know the answer.

The CHAIRMAN. I am just advised that radar sensitivity varies as the distance raised to the 4th power. So you are going to have a huge amount of additional power from the additional increase in distance.

On the other hand, these sensors are extraordinarily sensitive, and they are supposed to be able to read a license plate at 100 miles. I do not know whether they can or not.

Mr. HIRSCH. Not by radar at any rate.

The CHAIRMAN. But it is your testimony that with respect to this debris, that the debris would be completely burned up as opposed to coming down———

Mr. HIRSCH. Oh no, no. I misunderstood your question. You cannot predict the particle size. There will be a distribution of particle size if they would impact with space debris, have a power excursion or be hit by an ASAT.

Some would be large chunks. Those might reenter in chunks. Some might be small enough that they burn up. I think there would be a distribution and it would be a function of the nature of the incident.

I in no way meant to say that any of these collisions would result in total burnup. It is quite credible that fragments of some varying size would return to earth.

The CHAIRMAN. Well, if you had one of these sizes, let us say it came down the east coast, just streaked right down the east coast, burning as it came and finally lodged in the capital.

Now, I take it there would be some pieces breaking off as it came down. Or would there? Can you tell me the mechanics of that?

Mr. HIRSCH. The question is would part of the structure act as a heat shield, protecting the inner components from burnup? And in the Cosmos 954 situation, that appears to have happened for some of the material. It depends again on the size of the fragments.

If it were SP–100, for example, which is supposed to have a heat shield, and it fragmented, some of the material may still be protected by that heat shield and you may have large chunks.

In the case of Cosmos 954, some of the chunks were at about 500 rem per hour, on contact.

The CHAIRMAN. Really, what I am getting at is, we have sort of two ways to enter. One is it burns up and is dispersed globally, and the other is a hot chunk hits you.

Is there not an intermediate ground, an intermediate state, where smaller pieces might be at a heavier concentration in the area where it came down, maybe aerosol pieces that could be breathed by people on the east coast?

Mr. HIRSCH. Yes, yes. That is possible.

The CHAIRMAN. And the fact is we do not know?

Mr. Hirsch. Correct. The only way to know is to have a few hundred accidents and be able to then figure out what fraction of those occur in what way and what fraction occur in others, which is, of course, a lousy way of finding the answer. I am afraid there is no other way.

These are not accidents that are easily modeled. You could have the possibility of all three options, total burnup, partial burnup, or big chunks.

The Chairman. Is it worthwhile to have talks with the Soviets on trying to retrieve crippled orbit things that are already in space? Or you say the hook might not work. Is it worthwhile even pursuing that for those that are already there?

Mr. Hirsch. For the ones that are there? The ones that are there are in what we call nuclear-safe orbits?

If your question is related to protecting them against possible collision with space debris, Nicholas Johnson has proposed that there be some retrieval of that garbage up there, and propelling it way away from the earth. That might be worth discussing.

The Chairman. But it is not worth discussing a plan to retrieve them from low earth orbit.

Mr. Hirsch. Our review, after careful consideration of this, is that that option provides only marginal resolution of the risks associated with space nuclear power.

Senator Bumpers. I am sorry, Mr. Chairman.

The Chairman. I was finished.

Senator Bumpers. Mr. Hirsch, how many nuclear power satellites are there in orbit right now? Both United States and Soviet?

Mr. Hirsch. In excess of 30. And some of them have broken into subcomponents.

Mr. Aftergood. There are nine U.S. spacecraft carrying nuclear power sources. All but six I believe of them are not operating. There have been——

Senator Bumpers. But they are still up there?

Mr. Aftergood. They are still up there, yes. There have been 30 plus, maybe 34 RORSAT-type satellites put up by the Soviet Union, barring the ones that reentered.

And since Cosmos 954, they have split up, they have separated the core from the remainder of the satellite, and so there is in excess of, I believe, 40, probably something like 48, something like that, for which the Soviets are responsible.

Senator Bumpers. What right now is the technology we are using on our satellites, what is it, RTGs they call them?

Mr. Hirsch. We have not launched one for over a decade. We have not needed to. But yes, RTGs.

Senator Bumpers. What is the anticipated life of those power plants when we launch them?

Mr. Hirsch. The half-life is 87 years for the plutonium-238.

Senator Bumpers. I am not talking about the life of the uranium or the core. I am talking about the life of the satellite.

Mr. Hirsch. Before it reenters?

Senator Bumpers. No. When we launch, how long do we expect it to work?

Mr. Hirsch. That varies with each satellite. You will recall that a couple of our deep space probes, we were quite astonished to learn, are still operating far away from earth. It varies with each mission.

Senator Bumpers. What do the Soviets anticipate on their RORSATs?

Mr. Hirsch. Only a few months, but that is because of the orbit.

Senator Bumpers. I think Mr. Aftergood, you mentioned that SDIO is using 10 percent of their appropriations for nuclear power research. Is that right?

Mr. Aftergood. It is actually, Mr. Hirsch.

Senator Bumpers. Did you say that?

Mr. Hirsch. Yes. But he can say it also.

Mr. Aftergood. More specifically, roughly 10 percent of the combined SDIO and DOE budget, the portion of the DOE budget that is devoted to SDI-related work over the past several years has been devoted to nuclear technology, broadly speaking.

The majority of that has been for nuclear-directed energy weapons of which the X-ray laser is the best-known, and the remainder of that money we consider SDI-related is for space nuclear power, because in fact that is what the principal applications of it are.

Senator Bumpers. Can you tell me what percentage of appropriations you think is being used on chemical lasers for SDI purposes?

Mr. Aftergood. I am unfortunately the wrong person to ask about that. But there is a multi-megawatt program that is being handled by the Air Force that is devoted to non-nuclear, that is chemical power supplies, for future directed energy weapons.

Senator Bumpers. You do not know the comparison between the dollars?

Mr. Aftergood. I am afraid I do not know.

Senator Bumpers. Do you, Mr. Hirsch?

Mr. Hirsch. I do not. But one point I do want to make is that the nuclear use is not simply to run battle stations in terms of these directed energy weapons, but also to power sensors, to provide housekeeping power, a range of other uses. But I do not know the comparison.

The Chairman. May I interrupt?

Senator Bumpers. Well, I am finished.

The Chairman. Let me just ask this. I asked Colonel Hess about General Abrahamson's statement that without reactors in orbit there has got to be a very long, long light cord that goes down to the surface of the earth, meaning in effect that battle stations which require hundreds of megawatts and sensors which require tens of megawatts are going to have to have nuclear power to be effective.

Would you agree with General Abrahamson's statement that you have got to have nuclear power?

Mr. Aftergood. I think you have to make an adjustment for the audience he was speaking to.

To a certain extent he was telling the audience, the space nuclear power industry, what they wanted to hear, that there really is—you know, he was saying, trust me, there really is a mission for these things that you are working on.

I think the reality of SDI is unclear. What is the architecture? What systems are we talking about putting up? It is too ill-defined at this point to answer the question definitively.

The Chairman. Well, that is why I said battle stations with hundreds of megawatts and sensors with tens of megawatts. That pretty well says that it has got to be a beam weapon of some kind.

Mr. Aftergood. From basic principles the hundred-megawatt application for short periods could be provided by chemical means.

The long duration moderate power levels would almost certainly need to be provided by nuclear reactors, because anything else becomes impossibly heavy and expensive to launch.

The Chairman. Well, how about the sensors? Sensors you cannot just—I mean, they have got to be sensing all the time, do they not?

Mr. Aftergood. I think in the case of sensors nuclear power is a very attractive option, not only because of its reliability but also because it is inherently more survivable than the alternatives. But there is a certain amount of leeway as far as I can tell.

The Chairman. You really think you could have beam weapons in space through chemicals and not nuclear?

Mr. Aftergood. To answer the question precisely, I think the pulsing of the beam weapon could be non-nuclear powered. The supporting power for the platform would almost certainly need to be provided by a nuclear reactor.

So there are different levels of power. Some of them there is a consensus of opinion, in fact, by Office of Technology Assessment, the American Physical Society, and others, that nuclear reactors are required.

There is a question mark about the actual pulsing of the weapon, but maybe that is not important for your question.

The Chairman. You say there is a consensus that nuclear weapons are required?

Mr. Aftergood. Nuclear reactors, yes.

The Chairman. Well, that really was the question.

Mr. Aftergood. Okay, that also, by the way, is footnoted in my testimony.

The Chairman. Do you agree with that, Mr. Hirsch?

Mr. Hirsch. There is a consensus among OTA, DOE, Abrahamson's statement, and the American Physical Society. I think the fundamental point, though, is that no one knows what SDI is, what the architecture will be. Each month it seems they change the architecture.

If SDIO says they can do it without nuclear power and the President says the systems are going to be non-nuclear, I think that you ought to pull the plug on their nuclear bomb-pulsed systems and nuclear reactor-powered systems and let them meet that pledge.

The Chairman. I personally believe there is a lot more danger from SDI than there is from a reactor breaking up in space, although the latter may be a big danger. The danger from SDI is cosmic.

Mr. Hirsch. This may be a good way of being able to restrain that danger.

If I may make one policy point, two of the major contributions in the arms control area over the last several decades were the Limited Test Ban Treaty and the ABM Treaty. In my view, both occurred not so much because of what experts said in Congressional hearings and what Senators said on the Senate floor, but in large measure because at some point both of those issues came home to people in a way they could understand.

In the case of the testing issue, mothers were asked to send their children's baby teeth to scientists to monitor the Strontium-90 uptake. And when it was clear that this nuclear issue which strategists were talking about with words that were too long to get into newspaper articles, that in fact it was ending up in a nuclear form in our children's teeth, that created an upswelling of concern that ended atmospheric testing, in my view. The same thing is true with the ABM. What happened with the ABM was the concern about nuclear-tipped missiles in people's backyards.

Those who are concerned about SDI should address the reality of SDI being nuclear, not non-nuclear, The President understands what happened with the ABM Treaty and with the test ban. If it is in my backyard, if it is in my children's teeth, if it is nuclear that bothers people. The issue is clear, it is understandable then.

That is why he says SDI will not be in your backyard, it will be in space, and it will not be nuclear. The reality is it is nuclear——

The Chairman. It will not be cheap either.

Mr. Hirsch. It will not be cheap, right. But the reality is it is in our backyard because what goes into space often falls back, and it is nuclear.

The Chairman. Gentlemen, thank you very much. You have been very good in your testimony.

The final witness this morning is Mr. Charles A. Schmidt, Vice President and General Manager of Astro-Space Division of General Electric from Princeton. He is accompanied by Mr. J.S. Armijo, General Manager for Space Programs, and Dr. Jerry Peterson, Manager of Thermoelectric Programs of GE.

STATEMENT OF CHARLES A. SCHMIDT, VICE PRESIDENT AND GENERAL MANAGER, GENERAL ELECTRIC ASTRO-SPACE DIVISION, ACCOMPANIED BY J.S. ARMIJO, GENERAL MANAGER FOR SPACE PROGRAMS, GENERAL ELECTRIC; AND DR. JERRY PETERSON, MANAGER OF THERMOELECTIRC PROGRAMS, GENERAL ELECTRIC

Mr. Schmidt. Good morning, Mr. Chairman and Members of the Committee. I am Charles Schmidt, Vice President and General Manager of GE's Astro-Space Division. I am accompanied, as you said, today by Mr. Sam Armijo, the SP-100 program manager, and Mr. Jerry Peterson, manager of isotope programs.

I am pleased to have this opportunity to testify before your Committee. My written testimony has been provided to your staff, and I request that it be entered into the record of these hearings.

The Chairman. Yes, the written testimony will be entered, and we would prefer that you summarize.

Mr. Schmidt. Since GE is the systems contractor for SP-100, I will focus my comments on the SP-100 space reactor program.

It is increasingly evident that our nation's continued leadership in space will require reactor power. Reactor-based power systems are necessary to support missions requiring tens of kilowatts to hundreds of kilowatts.

As stated in previous testimony, the United States is developing through the SP–100 space reactor power system the technology to meet the projected civilian and defense needs for the 1990s and beyond. This technology will enable the fuller exploration and utilization of space.

GE as the systems contractor is supported by Westinghouse and Thermoelectron, eight of our nation's key government laboratories and several hundred subcontractors and vendors across the country. We are committed to making SP–100 a success.

In principle, the SP–100 power system produces power by converting the heat generated within a compact liquid metal cooled fast spectrum nuclear reactor directly into electricity through the use of thermoelectric conversion.

Liquid metal cooled fast reactors and thermoelectric conversion have been successfully developed in this country. We are capitalizing on this established technology base in this program.

Modularity is designed into this system to enhance scalability for specific missions over the tens to one hundreds of kilowatts range of interest without the need for additional technology.

Substantial progress has been made in this project. This past May, we successfully completed a system design review by nuclear, aerospace, safety and reliability experts from government and industry.

Nuclear fuel pellet fabrication development has been completed, and manufacturing of fuel for a nuclear systems test is currently under way at DOE's Los Alamos National Laboratory in New Mexico.

[The prepared statement of Mr. Schmidt follows:]

SENATE COMMITTEE ON ENERGY AND NATURAL RESOURCES
CHAIRED BY BENNETT JOHNSTON

TESTIMONY OF
MR. CHARLES A. SCHMIDT
VICE PRESIDENT AND GENERAL MANAGER
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SEPTEMBER 13, 1988

Statement of C.A. Schmidt
Vice President and General Manager,
GE Astro-Space Division
before the
Senate Committee on Energy and Natural Resources
September 13, 1988

Introduction

Good morning Mr. Chairman and members of the Committee. I am Charles Schmidt, Vice President and General Manager of GE's Astro-Space Division. I am pleased to have this opportunity to testify before your committee. My written testimony has been provided to your staff and I request that it be entered into the record of these hearings. Since GE is the systems contractor for SP-100, I will focus my comments on the SP-100 Program and in particular, the key safety features being implemented.

THE NEED FOR NUCLEAR REACTORS IN SPACE

It is becoming increasingly evident that our nation's continued leadership in space will require nuclear reactor power. Many ambitious space missions of the future required to assure this leadership will need a reliable source of electrical energy that exceeds the capabilities of current technology. While nuclear Radioisotope Thermoelectric Generators (RTG's) and solar systems can provide watts to kilowatts of power, reactor based power systems are necessary to support missions requiring tens of kilowatts to hundreds of kilowatts. Nuclear reactor systems also provide independence from the sun, long life and increased survivability advantages.

THE SP-100 PROGRAM

The United States, under sponsorship of the Department of Energy, the Department of Defense and the National Aeronautics and Space Administration, is developing SP-100 space reactor power system technology to meet the projected civilian and defense needs for the 1990's and beyond. SP-100, will remove the restrictions on electrical power generation that have limited space missions and will enable the fuller exploration and utilization of space. GE, as the systems contractor, is supported by Westinghouse and ThermoElectron, eight of our nations key government laboratories and several hundred subcontractors and vendors across the country.(Reference Figure 1) GE and its team members are committed to making SP-100 space nuclear power a success. We have made and are continuing to make investments in new production and laboratory facilities to assure timely development of the technology and our ability to support future flight options.

Before I address the specific safety aspects of the program, I would like to briefly bring you up to date on the design characteristics of the system and its present state of development. The SP-100 power system (Reference Figure 2), converts heat generated within a compact liquid metal cooled fast spectrum nuclear reactor directly into electricity through the use of thermoelectric conversion. Liquid metal cooled fast reactors have operated safely in this country and around the world for many years. For example, the EBR-II reactor in Idaho has been operated very successfully for over 20 years. We are capitalizing on this solid technology base. Thermoelectric conversion technology, used on SP-100, is also based on over 20 years experience. This technology was used with great success in powering experiments placed on the moon on the Apollo Program in the early 1970's.

In the SP-100 design, the heated liquid metal coolant is pumped from the reactor through a closed heat transfer loop to the thermoelectric modules. Excess heat is rejected to space by heat pipe radiator panels. An important feature is the modularity designed into the system to enhance scalability for specific missions throughout the 10's to 100's of kilowatt range of interest, without the need for new technology.

Substantial progress has been made on this project. This past May, we successfully completed a system design review by nuclear, aerospace, safety and reliability experts from government and industry. Nuclear fuel pellet fabrication development has been completed and manufacturing of fuel for a nuclear system test is currently underway at DoE's Los Alamos National Laboratory in New Mexico. Fuel life tests and core physics experiments are being conducted in DoE reactors in Washington and Idaho. Tests to date have been very successful. High temperature materials development is being conducted at DoE's Oak Ridge National Laboratory in Tennessee, NASA's Lewis Research Center in Ohio and at GE and Westinghouse facilities in California and Pennsylvania. Finally, there has been major progress in preparing facilities at DoE's Hanford laboratory in the State of Washington, for key nuclear system tests in 1992.

Significant progress is also being made in the development of advanced thermoelectric convertors, materials and insulators at GE facilities in Pennsylvania and at ThermoElectron facilities in Massachusetts. Heat pipes, capable of being mass produced, have been successfully tested in GE laboratories in Valley Forge.

Major subsystems and components will be tested on the ground in a simulated space environment to demonstrate compliance with safety, reliability and performance requirements. Major modules of the power system, including the thermoelectric power conversion and heat rejection subsystems are planned for testing as an integrated assembly in a large vacuum chamber at GE facilities in Pennsylvania in 1994.

SPACE NUCLEAR POWER SAFETY

GE has had a major role in space nuclear power programs for more than twenty years. Safety is and will continue to be of utmost importance to GE in the design, development, test and flight of space nuclear power systems. To date, the United States has launched 38 Radioisotope Thermoelectric Generators and one reactor. We should recognize the reliability and safety record of the RTG's which have provided power for key United States missions, including the Apollo manned lunar missions and the recent flyby explorations of Mars, Jupiter, Saturn and Uranus. The Voyager spacecraft is in its 11th year in space and presently over 2 billion miles from earth on its way to Neptune. Without this nuclear technology, this mission could not have been accomplished. RTG's are soon to power the Galileo and Ulysses science missions.

The Government, through the Interagency Nuclear Safety Review Panel, evaluates each proposed U.S. launch involving a space nuclear power system to provide an independent and final confirmation of the safety of the system. This process has been instrumental in the excellent safety record achieved. This same process would be implemented on the SP-100 flight program.

THE SP-100 SAFETY PROGRAM

At the onset of the SP-100 Program, the government, represented by DoE, DoD and NASA personnel as well as National Laboratory experts began developing a comprehensive set of Safety Requirements. These requirements were based on experience from the U.S. RTG missions, the SNAP-10A and Soviet space nuclear programs an well as extensive terrestrial nuclear and spacecraft mission experience including the deliberations of the UN Working Group on the Use of Nuclear Power in Space. These safety requirements were extensively reviewed by industrial participants including GE and Westinghouse and by independent experts. This process has resulted in a set of safety requirements and strategies now in use on SP-100 that assures the primacy of safety to the public, as well as protection of the environment, and the safeguarding of the special nuclear material.

The approach used to implement safety on the program consists of two main elements. The first is to identify the hazards and to incorporate features that are designed and tested to prevent accidents involving these hazards. The second element focuses on selecting the basic design and operational parameters to make the radiological consequences of postulated accidents a small fraction of natural background radiation. These consequences are summarized in Figure 3. This process has resulted in features that are an integral part of the design to ensure safety throughout all mission phases.

The basic safety requirements for SP-100 are as follows:

1. The reactor is to be kept free of hazardous radioactive materials until its prescribed operational orbit is achieved. To accomplish this, the reactor core will not

operate or generate radioactivity prior to achieving the prescribed orbit. The core is designed to prevent criticality under launch and ascent failure modes. A secure command and control communications system will be provided to prevent unauthorized startup and operation.

2. Orbits to be selected for the initial flights will provide time for decay of radioactive material to negligible levels before reentry could occur. While reentry of the reactor from a long life orbit would not constitute a radiological hazard, the SP-100 design approach allows for boosting of the spent reactor to a disposal location in space.

3. The reactor will be designed to return to a subcritical state and remain subcritical and intact even after accidental reentry and impact.

We have developed the generic flight system design with safety features based on these requirements. We have evaluated all mission phases including assembly, transportation, launch, ascent, transfer to operational orbit and end of mission disposal, and assessed the adequacy of the design. We have concluded the system will be safe.

I would like to describe some of our key safety features (Reference Figure 4). Two independent nuclear control features have been incorporated into the SP-100 design to ensure that the reactor remains inoperable until in its planned orbit. These systems will be designed to prevent operation of the reactor if launch accidents were to occur. Until operation, no radioactive materials are generated, and during operation radioactive materials are contained in the reactor and are above the earth's atmosphere and pose no hazard.

The reactor is also designed to retain structural integrity for all credible accidents in space. After completion of its mission, permanent shutdown features have been incorporated and the natural decay of radioactivity to negligible levels would occur prior to the spacecraft's natural orbital decay. As stated earlier, this would constitute no nuclear hazard. If the system were to accidentally reenter the earth's atmosphere, it will remain inoperable and survive reentry and impact essentially intact, through the use of high temperature structural materials and a reentry shield specifically designed for this purpose.

Our safety experts conclude that the radiological consequences of planned as well as unplanned SP-100 events will be very small. For example, if an SP-100 reactor operates at full power and subsequently reenters the earth's atmosphere after a 300 year orbital decay, the radiation exposure to a person standing 3 feet away from the reactor for an hour would be less than a chest x-ray.

I can say with confidence that adherence to the safety design and operational strategy and requirements of the SP-100 program will result in power systems that can be safely used in space. The design, testing and safety review process established for application to the SP-100 program will provide this assurance. Within the program there is an Independent Safety Advisory Committee comprised of nuclear and aerospace safety experts drawn from universities, industry, National Laboratories and private institutions. This group participated in critiquing the safety aspects of the SP-100 system in a major design review this past May. In addition GE has established its own separate Safety Advisory Board to provide independent counsel to management. We would not conduct a program without taking every step to assure human safety. To do otherwise would risk our Corporate reputation. Safety on the SP-100 Program stands alone as a primary objective and GE is committed to relentlessly pursue a safe design.

IMPLICATIONS OF COSMOS 1900

Before I conclude, I would like to take a brief moment to address the Soviet space reactor situation, specifically the possible reentry of Cosmos 1900 reactor and what impact such an event may have and more appropriately should have on the U.S. SP-100 Program.

Reentry of this reactor from space quite naturally will raise the attention and concern of the public. The U.S. Government and industry not only must clearly communicate the benefits of nuclear power and its importance to space leadership, but provide convincing evidence that the U.S. program has important differences as contrasted with the Soviet program; differences which provide significant safety improvements.

Cosmos 1900 has operated in a short lived low orbit and has lost communications with the ground and the reactor may reenter in the near future. In contrast, initial SP-100 flights will not be operated until a prescribed orbit is achieved that assures radioactive material decay to negligible levels. In addition, an extended lost of communications would cause reactor shutdown. We believe these features constitute a significant difference between future use of SP-100 and current Soviet application of space nuclear power.

Cosmos 1900 would be the 3rd Soviet reactor to reenter. The Soviets continue to employ reactors in space and we should fully expect them to continue. They have a need that is best met by nuclear reactors and they are reaping the benefits that can be achieved by their use. Notwithstanding proposals of independent Soviet scientists and others to ban use of reactors in orbit, it is our understanding that the Soviets have had a vigorous space reactor program for many years and that their work in this area will continue.

CONCLUSIONS

In conclusion, I would like to restate our conviction that there is a need to develop a space reactor power capability as a national resource for the United States. SP-100 technology can provide power for space radars and surveillance satellites for military and civilian applications. Global communications can be enhanced, including the use of high power for direct broadcast satellites for total world accessibility. Power for materials processing on space platforms is afforded. Survivable power requirements associated with defense platforms is provided. Power can also be made available for exploration and establishment of manned bases on the lunar and Martian surfaces.

The SP-100 Ground Engineering System Program involves several years of systematic design, ground testing and analysis to properly develop and validate the materials and systems technologies for space nuclear power. Thus SP-100 is an enabling program that will establish a U.S. option to deploy follow-on flight systems yet in this century.

I want to reiterate, that GE and our SP-100 team members remain fully committed to the safe and successful development of this technology and continue to stand ready to serve the Department of Energy, Department of Defense and NASA in meeting future space power needs. We are convinced that safety is being assured in SP-100 through stringent requirements, good design, thorough testing and open review. We would like to count on Congressional leadership to bring these efforts to fruition.

Thank you for allowing me to present this brief overview of SP-100 and its important safety aspects to you. I will be happy to answer any questions which you may have.

SP–100 NATIONAL EFFORT

PRIMARY PARTICIPANTS

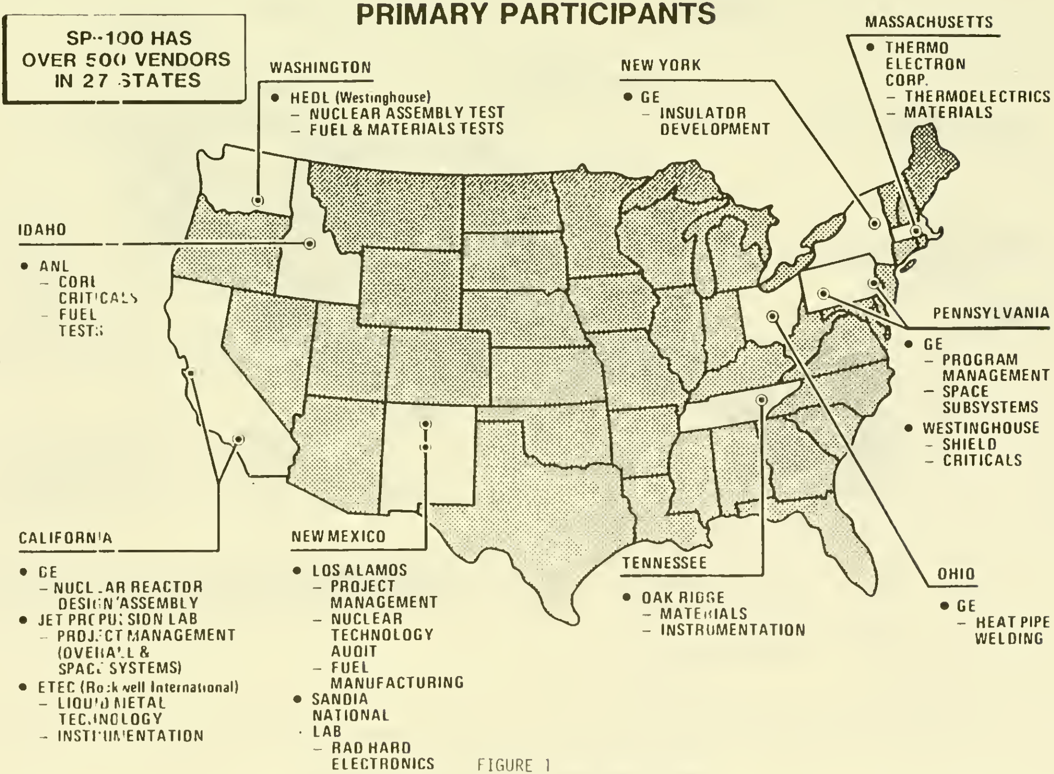


FIGURE 1

DEPLOYED CONFIGURATION

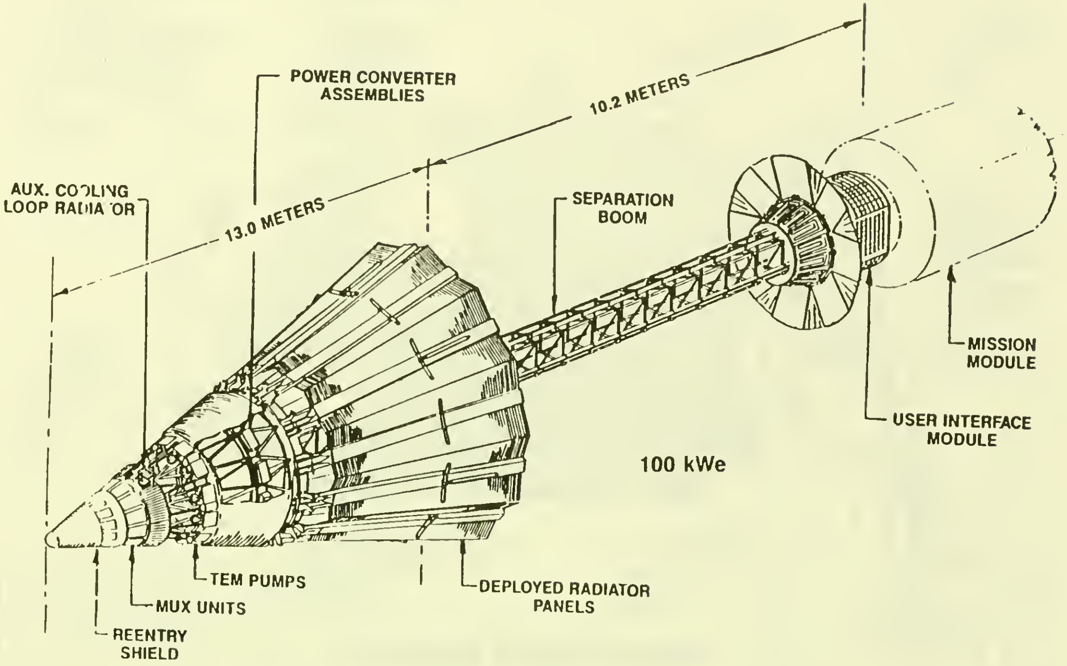


FIGURE 2

RADIATION CONSEQUENCES OF POSTULATED SP-100 ACCIDENTS

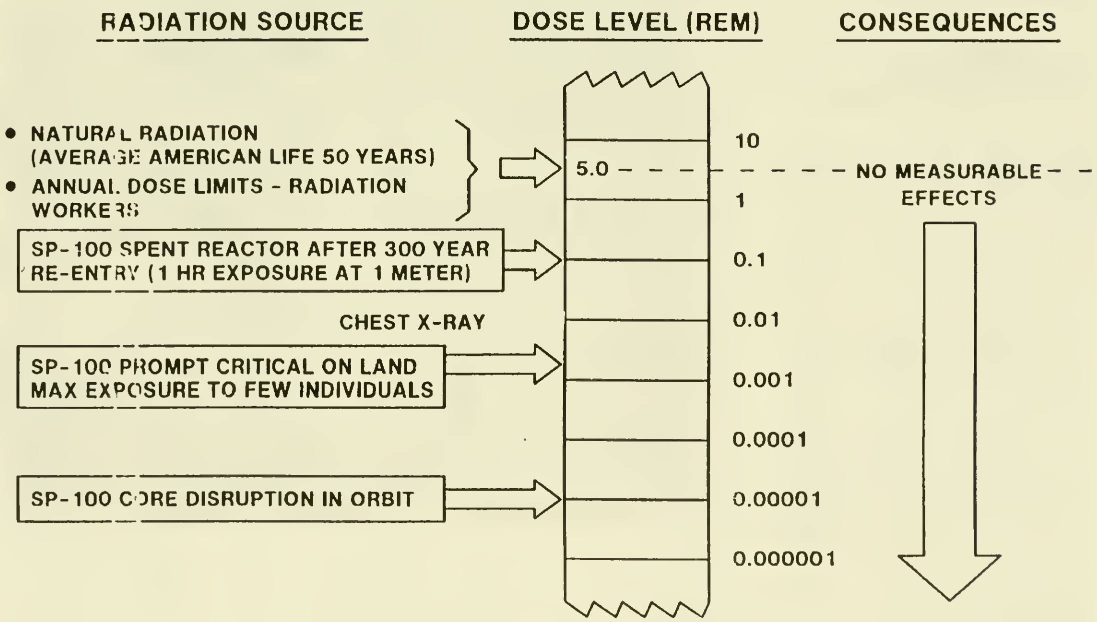
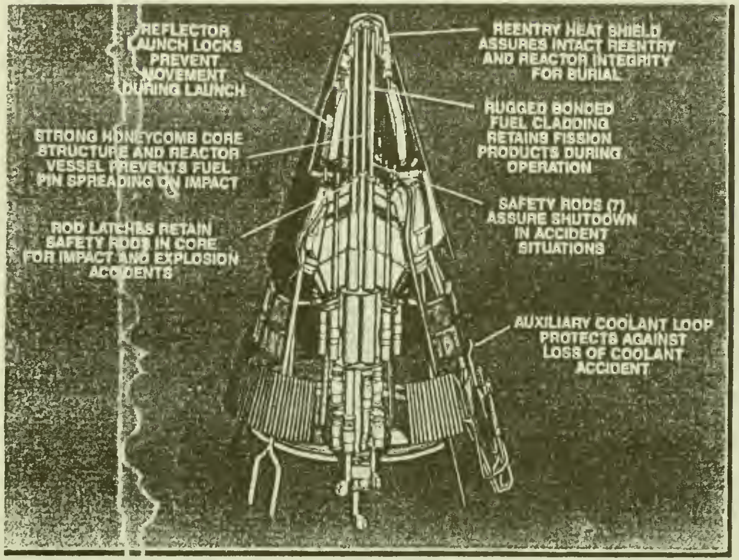

RADIATION SOURCE
DOSE LEVEL (REM)
CONSEQUENCES
• NATURAL RADIATION (AVERAGE AMERICAN LIFE 50 YEARS)
• ANNUAL DOSE LIMITS - RADIATION WORKERS
SP-100 SPENT REACTOR AFTER 300 YEAR RE-ENTRY (1 HR EXPOSURE AT 1 METER)
CHEST X-RAY
SP-100 PROMPT CRITICAL ON LAND MAX EXPOSURE TO FEW INDIVIDUALS
SP-100 CORE DISRUPTION IN ORBIT
10
5.0
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
NO MEASURABLE EFFECTS

FIGURE 3

KEY SAFETY FEATURES


REFLECTOR LAUNCH LOCKS PREVENT MOVEMENT DURING LAUNCH
STRONG HONEYCOMB CORE STRUCTURE AND REACTOR VESSEL PREVENTS FUEL PIN SPREADING ON IMPACT
ROD LATCHES RETAIN SAFETY RODS IN CORE FOR IMPACT AND EXPLOSION ACCIDENTS
REENTRY HEAT SHIELD ASSURES INTACT REENTRY AND REACTOR INTEGRITY FOR BURIAL
RUGGED BONDED FUEL CLADDING RETAINS FISSION PRODUCTS DURING OPERATION
SAFETY RODS (7) ASSURE SHUTDOWN IN ACCIDENT SITUATIONS
AUXILIARY COOLANT LOOP PROTECTS AGAINST LOSS OF COOLANT ACCIDENT

- CONTROL ELEMENTS AUTOMATICALLY SHUT REACTOR DOWN UPON LOSS OF POWER
- TWO INDEPENDENT SHUTDOWN SYSTEMS
- PROMPT NEGATIVE REACTIVITY COEFFICIENT ASSURES STABLE REACTOR CONTROL
- ONLY 4 OUT OF 12 REFLECTORS REQUIRED FOR SHUTDOWN
- CLEAN CORE AT LAUNCH
- LARGE NEGATIVE VOID COEFFICIENT ENHANCES SHUTDOWN UPON LOSS OF COOLANT
- CONTROL ELEMENTS MOVED INDIVIDUALLY AND IN INCREMENTAL AMOUNTS TO PREVENT RAPID REACTIVITY ADDITION
- RHENIUM POISON PROVIDES THERMAL NEUTRON ABSORPTION FOR WATER FLOODING

FIGURE 4

The CHAIRMAN. Mr. Schmidt, let me interrupt you at that point. We have got a vote at 12:22, and we do have your written statement in the record.

Let me ask you a couple of key questions here, because it is important that you have the opportunity to respond. It has just been stated by previous witnesses that if SP-100 fell to earth it could cause tens of thousands of fatal cancers, using the assumptions of the DOE contractor study. Would you respond to that?

Mr. SCHMIDT. Well, I would have my program manager for SP-100, who is much more familiar and can answer those questions more accurately.

Dr. ARMIJO. Senator, I do not know what the basis of their charge is. As you know, our system is designed to operate in high orbit, and in high orbit we would never expect these radioactive materials to reenter as according to our plan.

If it did reenter, we will have the protection of a reentry shield, the reactor is high temperature refractory metal container. The fuel is contained within very, very high temperature refractory metals. We designed the equipment so it will reenter intact and bury itself in the ground.

So I cannot see any way with those systems for tens of thousands of cancer deaths to result from that kind of accident.

The CHAIRMAN. All right, what do you say to their argument that you can have collisions in these higher orbits?

Dr. ARMIJO. There is a potential for space debris to strike the reactor even in the high orbits. The reactor has a certain amount of intrinsic hardness to damage.

We have also designed in a special coolant loop that would protect the reactor from overheating in the event that some space debris punctured the coolant and drained the coolant very rapidly. We have a secondary loop that keeps the reactor from overheating during that short transient when the coolant leaks out.

After that, the reactor would just stay there in space until its normal decay period was over, which will be several hundred years, and then it would reenter intact.

Now, there is a remote possibility, depending on the size of the debris particle, there is a remote possibility that the reactor could be damaged much more, and that would be enormous kinetic energy, which would destroy the whole spacecraft.

In that case, the fission products would be released in high orbit, and particles would also be formed, larger fragments would also be formed.

Our calculations indicate that it would take over 10 years for the existing radioactive fission products to get down through the atmosphere and onto the earth, and they would of course have been distributed over a very, very large area and an enormous amount of dilution would have occurred.

The CHAIRMAN. Well, if the worst accident happened and they were over a period of 10 years dispersed throughout the world's atmosphere, then an estimate of tens of thousands of cancer deaths would be wrong? Or——

Dr. ARMIJO. That would also be wrong. It would be far fewer than that.

And I would like to digress a little bit to——

The Chairman. Do you have a methodology to say how much? Or do you disagree with the basic premise that it can or cannot cause——

Dr. Armijo. Right. We disagree with the basic premise, Senator.

The way these calculations are made, I will give you a comparison. The methodology is based on a perception that there is no such thing as a safe level of radiation.

A parallel would be, consider a person who eats 100 aspirin. He is very, very likely to die. If you use the same methodology that there is no safe threshold level, if 10 people ate 10 aspirin, by that methodology one would die. If 100 people ate one aspirin each, one person would be expected to die by that methodology.

It is a flawed methodology, Senator. Unfortunately, we have gotten into the trap of using that over and over again. And it often misleads people into thinking there is danger when there is not.

The reality is that somewhere between one in four and one in three people on this earth are going to die from cancer deaths, and that is a large number.

The calculations when they tell you 200 people would die from cancer due to the radiation from this reactor, that is compared, that is using the super-conservative methodology, and that should be compared with millions and millions of people over that same time period which will die from natural cancer deaths. In all probability no one will die.

So I disagree with their methodology, and I disagree that they do not tell you the whole story.

The Chairman. Do I understand that methodology to be that they take the total cancer deaths and attribute them to background radiation?

Dr. Armijo. They take the extra little bit of radiation and they assume that it is every bit as lethal, independently of how it is distributed.

So they do not agree that there is a safe threshold of radiation. And we know that is wrong because there are different parts of this country where there is much higher natural radiation than here in Washington. And the cancer death rate is no different.

So there is a safe threshold level. Unfortunately, for conservative reasons, the nuclear industry has chosen to ignore that and design accordingly.

The Chairman. I think this is an important question because we get this question in all kinds of nuclear applications, other than just space orbits.

I wish you would, if you would, give us a written statement of why that methodology is flawed. And if perhaps Mr. Hirsch or Mr. Aftergood would like to respond and tell us why that methodology is not flawed, it would be instructive to us. I am not sure that you will come to a definitive conclusion on it, but at least we ought to look at that question.[1]

Now, let me ask you this. SP–100 preceded SDI, and there were anticipated applications for SP–100 before Star Wars was ever announced. Is that not correct?

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[1] See Appendix II.

Mr. SCHMIDT. Yes, sir.

The CHAIRMAN. And what were those applications?

Mr. SCHMIDT. Well, sir, the applications today for civil use are of course some of the ones that were mentioned here already, things like manufacturing in space where large amounts of power, if you ever do that, practically are required, and the cost of taking weight to space in other than nuclear energy sources is just prohibitive.

And we know that today that a pound of satellite into geosynchronous orbit takes 6,000 pounds of rocket. And you just cannot keep that up and say that you are going to do anything practical in lieu of some nuclear power source.

So there is that kind of thing of manufacturing in space. There is electric propulsion that can be powered by nuclear power to take deep space orbits or lunar and Martian missions. There are many things in the minds of our scientists.

And what I would like to point out, which I think is an important factor, is that the presently-contracted SP–100 effort does not produce the space demonstration. It is an enabling program to develop the materials and technology for the broad range, I think, of future flight systems requiring nuclear reactor power.

It is the necessary first step toward a space reactor. And what it does for the United States, I believe, is to provide the option that will permit space deployment yet in this century.

And if we fail to preserve this option, then the U.S. leadership in space I think will be severely damaged, and the space program visions of today will be accomplished by others.

The CHAIRMAN. Senator Bumpers?

Senator BUMPERS. I have no questions, Mr. Chairman.

The CHAIRMAN. Well, it so happens that they are just at that moment sounding the gong for the vote.

Mr. Schmidt, thank you for your testimony. We will of course have your written statement for the fuller explanation. Thank you very much.

[Whereupon, at 12:21 p.m., the hearing was adjourned.]

APPENDIXES

Appendix I

RESPONSES TO ADDITIONAL QUESTIONS

U.S. Senate,
Committee on Energy and Natural Resources,
Washington, DC, October 17, 1988.

Col. Henry G. Culbertson III,
Chief, Space Control Operations Division, U.S. Space Command, Colorado Springs, CO.

Dear Colonel Culbertson: I would like to thank you for your recent appearance at the hearing held by the Committee on Energy and Natural Resources on September 13, 1988 on "Cosmos 1900 and the Future of Space Nuclear Power".

This complex subject is worthy of additional commentary for the record. Accordingly, the attached question and your response will be included in the hearing record. I would appreciate your sending your response to Jim Bruce of my staff by November 11, 1988.

Again, thank you for your testimony. I look forward to your additional thoughts on this issue.

Sincerely,

J. Bennett Johnston,
Chairman.

Additional Questions From Senator McClure, September 13, 1988, Hearing: Cosmos 1900

QUESTIONS FOR COL. CULBERTSON

1. As you know, it has been suggested that nuclear reactors be banned from earth orbit. Please comment on what impact, if any, such a ban might have on your agency's proposed missions.
2. What uses do the Soviets now have for their nuclear-powered space satellites? Does the U.S. have similar capabilities? If not, doesn't this put us at a significant disadvantage in terms of national security and deterrence capabilities?
3. Are there potential DOD missions other than SDIO missions?
4. Are there any DOD-mission "critical areas" (e.g., survivability, performance) for which nuclear power would significantly outperform other alternative energy sources?

[Committee note.—Responses to the above questions were not received at the time the hearing went to press.]

Department of Energy
Washington, DC 20585

November 23, 1988

Honorable J. Bennett Johnston
Chairman
Committee on Energy
and Natural Resources
United States Senate
Washington, D.C. 20510

Dear Mr. Chairman:

On September 13, 1988, Dennis A. Bitz, Deputy Assistant Secretary for Space and Defense Power Systems, Office of Nuclear Energy appeared before your committee to discuss Cosmos 1900 and the future of space nuclear power.

Following that hearing, you submitted written questions, including questions on behalf of Senator McClure, for our response to supplement the record. Enclosed are the answers to those questions. A copy of the responses to Senator McClure's questions also has been sent to him.

If you have any questions, please have your staff call Michael Gilmore on 586-4277. He will be happy to assist.

Sincerely,

Rebecca A. Thompson
for Robert G. Rabben
Assistant General Counsel
for Legislation

Enclosures

QUESTIONS FROM SENATOR JOHNSTON

Question #1: What do you estimate has been the total cost to the U.S. Government to prepare for the possibility that Cosmos 1900 might fall to earth in a hazardous manner?

Answer: Planning for COSMOS 1900 reentry was conducted with available personnel who were diverted for limited periods from their primary responsibilities. An estimate reflecting salaries, travel and similar expenses for planning meetings, preparing plans and procedures and for preparing to activate an operations center at a DOE field office totals approximately $240,000. These activities, including the placing of various equipment and special recovery services on standby, were absorbed within the existing DOE budget. Since there was no deployment of resources, there was no additional expenditure of funds.

QUESTIONS FROM SENATOR JOHNSTON

Question 2:	Had Cosmos 954 come to Earth in a populated area, such as Manhattan, what dangers would have been posed?
Answer:	The principal consequences associated with a COSMOS 954 type reentry over a populated area would be (1) contamination of buildings and the ground; (2) risk of people contacting highly radioactive particles or debris; and (3) actual physical injuries from being struck by falling debris.

Less than 100 pieces of radioactive debris, ranging in size from a few grams to several kilograms, would be expected to reach the ground. Therefore, although a large area would be expected to be contaminated, these large pieces could be located and removed. Based on a Canadian report on COSMOS 954, the impact on the environment of unrecovered particles would likely be insignificant when compared with the fallout deposition that exists currently.

The 50 to 100 pieces of debris which would have significant radiation fields associated with them would have differing aerodynamic characteristics, which would spread out the pieces, so that no one person would likely be exposed to more than one piece. Consequences would likely be limited to radiation burns, but could conceivably range up to a lethal

Answer 2
(continued):

radiation dose; this would only be for a particularly "hot" piece and extended exposure.

Actual physical injuries from being struck by the debris would be directly related to the population density of the impact area. Although space debris reenters the earth's atmosphere daily, there has never been a recorded case of an injury resulting from such debris. The probability of such injury may be roughly compared to aircraft crashes in populated areas, which usually result in few, if any, deaths or injuries to those on the ground.

Finally, based on the COSMOS 954 cleanup, particles were found to be largely insoluble in water and in dilute acids which approximate digestive juices. Field investigations resulted in no detectable contamination of air, drinking water, soil, or food samples.

QUESTIONS FROM SENATOR JOHNSTON

Question #3: Suppose, as was suggested in the hearing, an SP-100 nuclear reactor through an extraordinary chain of events fell to Earth in Libya.

Suppose further that prior to its descent, the reactor had been turned on and had operated in orbit for a period of time, so that it was highly radioactive.

(a) How difficult would it be for the Libyans, for example, to recover the fissionable material and to make a nuclear bomb from it?

Answer: Reentry in Libya would be highly unlikely. An estimate of the probability of mission failure with impact in Libya is less than 1 in 10 million. Assuming a mission failure did occur, the probability of impacting Libya is about 1 in 1000. For orbits close to equatorial, the estimate of impact in Libya is essentially zero because the reactor does not pass over its territory.

Nevertheless, if a reactor did fall in Libya and that nation should try to make a nuclear bomb, the following points would have to be considered.

A reactor that had operated for some time and impacted the earth soon after operation would be highly radioactive. Without shielding and remote handling devices, recovery and transport of the reactor would be very dangerous to the people working with it.

Answer #3
(continued):

Theoretically, a nuclear bomb may appear to be a deceptively simple device. Two subcritical masses are driven together into a supercritical mass that releases nuclear energy. In practice, however, building a successful bomb of significant yield is a sophisticated, complex engineering feat. Depending on the materials, design, fabrication, and assembly, the relative yield or energy released will vary from a low to a high amount.

It is extremely complicated to build a nuclear bomb when using fuel which has been irradiated, because it would take greater expertise and facilities than would be necessary for unirradiated fuel to separate the fuel from the fission products. A team of highly skilled and knowledgable scientists, engineers, and technicians would be required to design and fabricate a weapon. A technology base would be needed to support the interrelated mechanical, electronic, materials, instrumentation, and nuclear specialties.

Physical facilities for fabricating such devices, including specially manufactured materials, would be needed. If the facilities, staff and program were already in place, it is estimated by a DOE weapons laboratory that many months would be required to produce a weapon from the SP-100 fuel. If the resources were not already in place, it could take years.

Answer #3 (continued): (b) What kind of facilities would be required to handle the material and to process it?

Answer: Hot cells, i.e., shielded cells with controlled atmosphere and remote handling equipment, would be needed to contain and operate the chemical separation equipment needed to extract the usable fuel from the highly radioactive fission products. Continued operation and maintenance of the processing facility is a major engineering endeavor once it is contaminated.

(c) Please explain what chemical processing would be required to separate out the fissionable material and what additional processing would be required to convert the material to weapons grade.

Answer: Chemical processing to separate the fissionable material from the highly radioactive fission products, such as the Purex process, would be required; no additional processing would be needed to convert the material to weapons grade. Because of the highly radioactive material, processing must be done in specially shielded facilities, thus complicating the process.

Answer #3 (continued):	(d) Could a simple "gun-type" bomb be made to work using this material? Could any other type of nuclear bomb be made from it?
Answer:	It is very important in the operation of a "gun-type" bomb to ensure that the fuel does not contain material which is a source of neutrons. If neutrons are present within the fuel they can cause the bomb to preinitiate and not be effective. Uranium fuel which has been irradiated will contain material which release neutrons, thereby not making it possible to make an effective "gun-type" bomb.

It may be possible to use the uranium fuel for the core of an "implosion-type" bomb, once the difficult task of removing the fission products had been completed, but it is highly unlikely that this would be an effective weapon. An "implosion-type" bomb is based upon extremely sophisticated design, electronics, and construction principles.

In summary, the probability of reentry of an SP-100 reactor in Libya is extremely low because of the operating orbits and the low probability of failures. The engineering feat required to convert the fuel to acceptable weapons-grade

Answer #3 (continued):	material and construct a weapon is time consuming, hazardous, and very complex.
	(e) How would the answers to questions (a) through (d) change if the reactor had never been turned on before it fell to earth?
Answer:	If the reactor had never been operated, there would be no danger from exposure to radioactive materials and thus no requirement for remote handling. No plutonium would be present. The minimum time for developing a weapon would decrease to a few months. This would still allow sufficient time for retrieval.

QUESTIONS FROM SENATOR JOHNSTON

Question 4: A later witness, Stephen Aftergood, quoted a DOE representative as testifying before a House Committee that the U.S. Government would not start a nuclear reactor in space until the reactor obtained a "nuclear safe orbit."

a) Was there such a pledge?

Answer: Several years ago DOE officials did use that term, based on the preliminary safety requirements in effect at that time.

b) Has this policy changed, and if so, when and why?

Answer: This policy has been further defined as greater understanding of reactor design and safety issues has been achieved. Under the current approach, only orbits in which the reentry time of the spacecraft is sufficiently long to allow decay of the radioactive fission products to low levels will be considered. The term nuclear safe orbit is no longer generally used because there is no agreed-upon single definition for this term.

The buildup and the rate of decay of fission products is directly related to the reactor power level and the length of time of operation. Therefore, there is no single orbit which

Answer 4 (continued):	can be classified as "nuclear safe." Rather, each mission must be reviewed on a case-by-case basis, where acceptable orbits will be defined according to the operating history of the reactor.
	c) What is the current policy of the U.S. Government on this point with respect to future launches of nuclear reactors in space?
Answer:	As stated in Part b, the minimum acceptable operating orbit must be evaluated on a case-by-case basis. Indepth safety analyses are required to verify that if the system were to accidentally reenter, it would have had sufficient time to allow the decay of the fission products to sufficiently low levels. Each mission is unique and must be analyzed individually. Some missions may require operating in the shorter lived orbits because of the mission objectives and limitations. As an example, if nuclear power were to be used in a material processing laboratory, a lower orbit would be required to be able to retrieve materials using the shuttle system. An indepth safety analysis and independent review must be

Answer 4 (continued):	completed before any mission is given approval for launch. The sponsoring agency must verify that it is sufficiently safe to use the nuclear power system as designated in the mission operating scenario from launch to final disposal. Therefore, each sponsoring agency will have to ensure that the orbit or orbits in which the nuclear power system will operate are "nuclear safe", given the mission operating scenario.
	(d) What potential missions would involve the operation of nuclear reactors in space in other than nuclear safe orbits?
Answer:	Sustained, low earth orbit operation is one potential mission of significant future interest, especially in the area of space-based materials processing facilities that exploit the highly advantageous microgravity conditions of space. Large-scale commercial activities in the microgravity environment will require large amounts of electrical energy that can be delivered by a nuclear reactor.

QUESTIONS FROM SENATOR JOHNSTON

Question 5:	What is the expected cost of the first demonstration flight of SP-100 and what is included in that cost?
Answer:	Since a flight demonstration mission has not been specified as yet concerning experiment, equipment and operational requirements, no meaningful cost estimate has been made. However, such a cost estimate would include the cost of production equipment, fabrication, assembly and flight qualification of the hardware, including safety, as well as the spacecraft integration and launch costs.

QUESTION FROM SENATOR JOHNSTON

Question #6: The DOE had a contractor prepare a risk assessment of Cosmos 1900 reentry, did it not? Please provide a summary of that assessment. In particular, please describe what was the anticipated radiological risk. Later witnesses discussed the radiological risk posed by Cosmos 1900 in terms of potential cancer deaths, ranging from 0 to several hundred. Would you comment on this assessment?

Answer: NUS Corporation has prepared NUS Report 5148, A Pre-Boost Risk Assessment of Cosmos 1900, dated October 17, 1988, under contract to the U.S. Department of Energy. A copy of that report is hereby provided for the record. The summary and conclusions section (pages 2.1 and 2.2) is attached to this answer. It shows that calculated excess cancer fatalities would be less than one, and could range between 0.005 and 0.18 for three possible scenarios.

With regard to assertions by other witnesses that the radiological risk could range up to several hundred cancer deaths, we do not believe these assertions to be accurate, as described in the following answers.

Answer #6 (continued):	(a) In particular, Mr. Aftergood cites in his testimony a study conducted in 1979 entitled, "Safety Assessment for Space Reactors," (NUS-3442, page 27, 51) as supporting the assertion that as many as 30,000 to 50,000 fatal cancers could possibly result from reentry and complete disintegration of a 1000 kw thermal reactor after 10 years of use. In your view does this study support this assertion? If not, why not?
Answer:	The cited study, sponsored by the U.S. Department of Energy in 1979, represented an early scoping and sensitivity analysis that can only be characterized as overly conservative. The conservative aspects of the analysis, as noted in the report, included the following:

1. The decay of radioactive fission products following reentry burnup was not taken into account.

2. A linear dose response model was used to relate population dose to health effects. Even though the radiation doses were much smaller than normal background, when summed over the worldwide population, these small radiation doses yielded large integrated population doses.

Answer #6 (continued): Other conservatisms included operational and accident scenarios, radioactive release fractions, and particle sizes.

The analytical approach was limited by the computer models available at that time to treat the complex time-dependent nature of the problem, which coupled radioactive decay of the radionuclide inventory following reentry and time-dependent mass transport of material through the environment. Since that time, the Department has developed an improved methodology with a supporting computer program to adequately perform more realistic risk assessments of space reactor systems.

The updated methodology, coupled with the new computer model, removed the unrealistic conservatisms of the previous scoping analysis (NUS-3442), resulting in a more realistic analysis and a reduction in the calculated radiological consequences of postulated accident scenarios by many orders of magnitude. The use of the updated methodology is reflected in the current risk analysis of space reactor systems performed by NUS Corporation for the Department.

Answer #6 (continued):

(b) If one were to extrapolate the results of the study cited in (a) above, what would be the number of cancer deaths from a Cosmos 1900 under these circumstances?

Answer:

As stated in Response 6a, the conclusions stated in NUS-3442 are considered no longer valid in light of the improved risk assessment methodology. Using the more accurate assumptions, DOE would not agree with any extrapolations of NUS-3442 in estimating Cosmos 1900 risks. Given the latest report prepared by NUS Corporation on Cosmos 1900 (NUS 5148), the risk from a COSMOS-1900 reentry is estimated to be 0.04 excess cancer deaths.

(c) Can the circumstances of the DOE contractor study cited above in (a) be used to estimate the potential number of cancer deaths, if any, attributable to an SP-100 reentry and burnup? If not, why not?

Answer:

Since the SP-100 design, operating periods, and mission profiles do not correspond to those addressed in NUS-3442, and due to the improved methodology discussed under Response 6(a), the results contained in NUS-3442 cannot be extrapolated or applied to SP-100.

A later witness, Mr. Hirsch, discussed the potential radiological risk of SP-100 as causing tens of thousands of cancers. Would you discuss this?

Answer #6
(continued):

Answer: Given the design, operational history and operating orbit of a SP-100, it is not plausible that tens of thousands of cancers could ever occur. A more realistic and yet conservative estimate was given in 6(b). Therefore, DOE strongly disagrees with the risk estimate of "tens of thousands of cancers."

2.0 SUMMARY AND CONCLUSIONS

This section summarizes the results of this study in terms of the radiological risk, debris risk, hazard to aircraft due to COSMOS 1900 prior to its successful reboost to a high orbit.

2.1 ACCIDENT SCENARIOS

Based on information provided in Reference 1, the following profile and accident scenarios are assumed for COSMOS 1900 for the purpose of this risk analysis:

1. The nuclear reactor operating period at full power is from December 12, 1987 to October 1, 1988.
2. On October 1, 1988 (time T) loss of attitude control is assumed, leading to activation of the safety systems. If reactor safety systems include provisions for shutdown when loss of altitude control is detected, separation of the kick stage with the nuclear reactor and reboost to the high orbit would be automatically attempted. The radar antenna and launcher second stage would promptly burnup upon reentry. Failing reboost, the second safety system would eject the core in the low orbit in a manner similar to COSMOS 1402. Sequence of events would then include prompt reentry burnup of the radar antenna at T + 2 days; reentry burnup of the launcher second stage and kick stage on T + 26 days; and the reentry of the ejected core at T + 41 days. Failure of all safety systems would lead to prompt reentry at time T, with partial reentry burnup as in COSMOS 954.

From a reliability viewpoint, the following assumptions are made:

1. Case 1: The probability of first safety system operating successfully resulting in reboost is 0.45.
2. Case 2: The probability of first safety system failing and second safety system ejecting core successfully as in COSMOS 1402 is 0.45.
3. Case 3: The probability that both safety systems fail with no reactor shutdowns, resulting in prompt reentry and partial burnup, as in COSMOS 954, is 0.1.

2.2 Radiological Risk

A radiological consequence analysis was performed for the above three cases as described in Section 2.1. The results were initially developed in parametric equation form for each case, so that if COSMOS 1900 would have reentered, the radiological consequences could have been calculated based on actual reentry conditions. Numerical results were also determined for estimated parameter values. The resulting radiological consequences for Cases 1, 2, and 3 were 5.15×10^{-3}, 4.76×10^{-2}, and 1.82×10^{-1} excess cancer fatalities, respectively, assuming a random reentry and a health effects estimator of 120 excess cancer fatalities per million person-rem.

Defining risk as the product of probability and consequences for each case, and summed over all cases, the pre-boost radiological risk is estimated to be 4.19×10^{-2}

excess cancer fatalities. Due to the successful reboost of COSMOS 1900 to the high orbit, the radiological consequences of COSMOS 1900 is estimated to be 5.15×10^{-3} excess cancer fatalities, corresponding to Case 1 with a probability of 1.0.

2.3 DEBRIS RISKS

The above risk analysis is based on a uniform population density, and does not address individuals approaching or picking up debris and fuel particles in the case of a partial reentry burnup, as in Case 3. Should COSMOS 1900 have had a partial burnup reentry as COSMOS 954 it is estimated there may have been 50 to 100 pieces of debris, not including fuel, with significant radiation fields associated with them (100 to 200 R/hr within 5 inches). In addition, fuel particles on the order of 100 to 1000 microns in diameter would have been scattered across a footprint with an approximate area of 50,000 km^2.

Exposure to reactor structural materials, and possibly reactor fuel particles could deliver possibly significant direct doses to individuals due to short term inadvertent exposure. These doses could range from those adequate to cause skin burns to much higher levels, depending on the length of the exposure and the strength of the radiation field involved. The number of people involved would be strongly dependent on population density and communication capability.

According to the Soviet Union, the problem of neutron activated components that survived reentry with COSMOS 954 would not have occurred with COSMOS 1900 due to a redesign. Therefore, the debris risks described above may be overstated.

2.4 AIRCRAFT HAZARDS

The probability of any debris (other then small particles) from a partial reentry burnup of COSMOS 1900, as in COSMOS 954 (Case 3), to aircraft operating within the debris footprint following reentry is estimated to be less than 2×10^{-10} per aircraft. This hazard is considered negligible. Furthermore, accumulation of small particulate fallout on aircraft surfaces is also estimated to be negligible.

2.5 RISK COMPARISON

The radiological risk of COSMOS 1900 has been compared to other previously reentered nuclear systems, including SNAP-9A, COSMOS 954, and COSMOS 1402. The total risks of these four systems were estimated to be 5.43×10^4 person-rem (6.52 excess cancer fatalities). The combined population dose risk of these systems is estimated to be 0.011 percent of the annual population dose due to natural background radiation. This assumes that the population dose risk of these systems accumulated in a single year. In reality, the population dose risk would accumulate over a period of years, so the percentage of background radiation would be far less than reported.

The radioactivity estimated released from the reentry of COSMOS 954, 1402, and 1900 (following reentry from long-lived orbit) combined represented 0.00096 percent of that due to global fallout from prior nuclear weapon testing.

QUESTIONS FROM SENATOR JOHNSTON

Question #7:	If a nuclear reactor was parked in a nuclear safe orbit and it was struck by orbiting debris, what is the likelihood that the collision would cause radioactive fragments to come directly back to Earth? To what extent would radioactive fragments come back to Earth sooner than otherwise would have been the case in the absence of a collision? How much sooner? Would those fragments survive reentry?
Answer:	The likelihood of a nuclear reactor being struck by orbiting debris with sufficient size and mass to break through the reactor's several layers of containment to the fuel is very low. There are essentially six layers of materials between the fuel pellets and space. Given an on-orbit collision of debris with a nuclear reactor in a "nuclear safe orbit," as mentioned in the question, the radioactive fragments resulting from the collision would have an orbital lifetime which would be a function of various characteristics, such as their area, mass and drag. In general, these fragments, individually, would have longer orbital lifetimes than the original reactor, and thus the time for the radioactive fragments to return to earth would be longer. Further, when the fragments did reenter, they would likely burn up from the reentry heating.

QUESTIONS FROM SENATOR JOHNSTON

Question 8: If the Soviet RORSAT satellites used a nuclear reactor as powerful as SP-100, how much higher, based on the tradeoff between altitude and radar power requirements, could the orbit be and still accomplish the satellite's mission? Could it operate in a nuclear safe orbit?

Answer: Information regarding missions and capabilities of the Cosmos 1900 series satellites has not been made available by the Soviets. Our assessment of these capabilities can be provided in a classified briefing. A radar satellite using US radar technology and the SP-100 as a power source would have very good resolution, even in orbits higher than employed by Soviet satellites such as Cosmos 1900. One U.S. proposal for space based radar would use a 300 kWe class SP-100 for its power source and would meet military resolution requirements while operating in geosynchronous orbit (around 35,000 km). This would certainly be considered a "nuclear safe" orbit.

QUESTIONS FROM SENATOR JOHNSTON

Question #9: What particle size distribution would be expected from burnup of reactors in the atmosphere? Would the sizes be similar to those found in the high atmosphere from nuclear explosives tests? Would any be respirable and if so, how long would it take before they reached the Earth's surface? Would they tend to be evenly dispersed over the Earth's surface?

Answer: The particle size distribution resulting from the reentry burnup of a reactor would be dependent on the reactor/spacecraft design, structural materials, and type of fuel.

Measurements taken following the reentry of Cosmos 954 indicated that 80 percent of the core vaporized at high altitude and 20 percent entered as debris.

Information provided by the Soviet Union to the International Atomic Energy Agency prior to the successful reboost of Cosmos 1900 included estimates that fuel particle sizes would have been in the range of 60 to 880 microns (compared to a respirable size of 10 microns), should reentry burnup have occurred. These fuel particles would be much larger than those found in the high atmosphere from nuclear tests. Particles of this general size would be expected to be evenly dispersed over the earth's upper atmosphere and therefore highly diffuse. The particles would take approximately 3 to 10 years to reach the earth's surface.

QUESTIONS FROM SENATOR JOHNSTON

Question #10: Are there any exposures that could conceivably occur in commercial aircraft if they passed through the "plume" of a nuclear reactor that unintentionally reentered and burned up in the atmosphere?

Answer: The probability of any debris (other than small particles) from a partial reentry burnup of a nuclear reactor striking an aircraft within the debris footprint following reentry is estimated to be less than two in ten billion per aircraft. This hazard is considered negligible. Furthermore, the probability of accumulation of small particulate fallout on aircraft surfaces, leading to exposures to radioactivity, is also estimated to be negligible.

QUESTIONS FROM SENATOR JOHNSTON

Question #11:	Please compare the inventory, especially of plutonium, strontium and cesium of various space reactors to that in fallout from an atmospheric weapons test. Please compare the integrated health effects of fallout from a space reactor burning up in the atmosphere to near-term and long-term fallout from atmospheric weapons tests.
Answer:	Generally, the radionuclide inventory associated with isotopes of plutonium, strontium, and cesium in a space reactor would be expected to be orders of magnitude lower than that associated with an atmospheric weapons test. The radionuclide inventories associated with space reactors will be functions of the reactor design, type of fuel, power level, operating period and shutdown period. Thus, much variation is to be expected. Estimates for Cosmos 1900 are provided in Appendix A of NUS Report 5148, which has been submitted for the record. The radionuclide inventories associated with atmospheric nuclear weapons tests have been summarized by M. Eisenbud in the book entitled, Environmental Radioactivity from Natural, Industrial, and Military Sources (Third Edition, Academic Press, Inc., 1987). The radionuclide inventory in fallout associated with an atmospheric weapons test will be a function of the weapon design and yield, so that direct comparison with space reactors is not feasible.

QUESTIONS FROM SENATOR MCCLURE

Question #1:	A senior Soviet scientist, Roald Sagdeev, has joined with U.S. scientists in proposing a ban on using reactors in orbit. Is this an official position of the Soviet government or just his own personal view?
Answer:	The views expressed by Dr. Roald Sagdeev appear to be his own personal views and not an official position of the Soviet Government. Dr. Sagdeev is a respected Soviet scientist who was the Director of the Soviet Space Research Institute, but retired from that position in September. There have been no initiatives by the Soviet Government proposing a ban on reactors in orbit, nor have there been any reports by Pravda or other Soviet sources proposing such a ban. On the contrary, on October 17, 1988, a TASS Science News Analyst, Nikolai Zheleznov, stated that Soviet scientists have analyzed the successful boost of COSMOS 1900, and have concluded that its success makes it possible to substantially reduce restrictions on the scope of application of nuclear power plants in outer space.

QUESTIONS FROM SENATOR MCCLURE

Question #2: Considering the fact that nuclear power has certain inherent safety concerns, such as the potential for the reactors to reenter the atmosphere and impact on earth, why are we not planning to use some other technology to supply future space power needs?

Answer: Future space power needs will be provided by several types of power sources, including solar, chemical, radioisotope thermoelectric generators and nuclear reactors. The radiation associated with nuclear power sources does give rise to safety concerns which must be convincingly addressed. Nuclear power can be safely used and remains the power system of choice for certain missions. Nuclear power possesses some inherent advantages over other power sources, including small size and weight for large power levels, independence from the sun, long lifetime, survivability against cosmic or manmade radiation, and ability to be made hardenable. But most importantly, nuclear power is absolutely essential if some NASA and DOD missions are to be accomplished; these missions cannot reasonably be undertaken due to cost or substantially increased number of required launches if nuclear power is not utilized.

QUESTIONS FROM SENATOR MCCLURE

Question #3: What are the milestones for SP-100? Should this schedule be stretched out somewhat in order to better suit the customers' timeframe for deployment?

Answer: The SP-100 Ground Engineering System (GES) Program, which will validate the space reactor power system technology, includes two major milestones. These are the Nuclear Assembly Test (NAT) and the Integrated Assembly Test (IAT). The NAT is a ground test of the SP-100 reactor; full power testing of the reactor is scheduled for completion by the end of calendar year 1992. The IAT, a test of the nonnuclear power conversion system, is scheduled for completion by the end of calendar year 1994. These dates support a launch capability in the mid 1990's and are consistent with the proposed SDIO electric propulsion flight experiment, the USAF Space Surveillance and Tracking System (SSTS) mission, and as the power source for other nearer term USAF missions. SP-100 is the reference power source for the electric propulsion flight experiment and is a potential power source for SSTS. The flight experiment is necessary to support Phase II milestones of the SDIO and to demonstrate the availability of this technology for projected NASA missions. A stretch-out of the SP-100 schedule may not be supportive of these missions and would increase total project costs.

QUESTIONS FROM SENATOR MCCLURE

Question 4: Who are the customers for multimegawatt space power? What are the missions?

Answer: SDIO will require high power for its primary weapons platforms. Currently, both nuclear and chemical systems are being considered. In the longer term, as the U.S. becomes more active in exploring and establishing settlements in space. NASA and other civilian users will need multimegawatt space reactor power systems to satisfy their growing space power demands. The multimegawatt system can provide burst power for the SDIO neutral particle beam, free electron laser and electro-magnetic launchers. It can also provide steady-state power for lunar and Mars settlements, as well as the distinct advantages of nuclear-electric propulsion for future manned and unmanned space exploration. A multimegawatt space reactor power system offers significant advantages over alternate power sources and is a leading candidate for many future military and civilian applications because of its inherent compactness, low weight, high survivability and hardness, high power output and long life capability.

QUESTIONS FROM SENATOR MCCLURE

Question #5: Is there a group within DOE assigned to coordinate customer needs with the various DOE activities in space reactor work? How many FTE's are assigned to this coordination task?

Answer: There is no current group within DOE which has the sole, specifically assigned duty of coordinating customer needs within the various DOE activities in space reactor work. This important function is conducted, however, along with other duties under the cognizance of the Deputy Assistant Secretary for Space and Defense Power Systems. In addition to this official's direct involvement in this important issue, he directs a group of about two dozen FTE's who manage the design, development, fabrication, testing, etc. of space nuclear power sources, and who continually coordinate customer needs with DOE activities as an ongoing part of their responsibilities.

QUESTIONS FROM SENATOR MCCLURE

Question 6:	In Steven Aftergood's statement, he states that DOE has abandoned its safety policy for a "nuclear safe orbit." Is this an accurate statement? Please explain.
Answer:	Only orbits in which the reentry time of the spacecraft is sufficiently long to allow decay of the radioactive fission products to low levels are considered. The term "nuclear safe orbit" is no longer generally used because, with the variety of user mission requirements, a single definition (such as orbit "height") is not applicable from the user perspective.

The buildup and the rate of decay of fission products is directly related to the reactor power level and the length of time of operation. Therefore, there is no single orbit which can be classified as "nuclear safe." Rather, each mission must be reviewed on a case-by-case basis, where acceptable orbits will be defined according to the operating history of the reactor.

QUESTIONS FROM SENATOR MCCLURE

Question #7:	Why haven't any space reactor systems been deployed in this country since the SNAP 10A program of 1965?
Answer:	The U.S. space reactor development program, which included the development and successful launch of the SNAP 10A reactor in 1965, was halted in the early 1970's due to lack of specific defined missions. Radioisotope thermoelectric generators and solar power units have successfully met the relatively low level space mission power requirements since that time. However, these are not practical technologies for the higher power levels expected to be required for both civilian and military missions. To meet certain NASA and DOD power requirements of the mid 1990's and beyond, the SP-100 space reactor development program was initiated in 1983. The SP-100 program, followed by the Multimegawatt program, will provide the high power levels required for future space missions.

QUESTIONS FROM SENATOR MCCLURE

Question 8:	Why do the Soviets use such low orbits in the first place?
Answer:	The Soviets characterize the mission of the Cosmos 1900 class of satellites as "scientific oceanographic studies." There is a relationship between altitude, power and resolution that drives the choice of orbits for this type of satellite. In general, the lower the orbit and the higher the power available, the greater the resolution. The fact that most satellites of this series have been flown at very low altitudes (around 250 kilometers) suggests that the Soviets desire very good resolution.

QUESTIONS FROM SENATOR MCCLURE

Question 9:	Can the use of Nuclear Electric Propulsion reduce launch cost? Please provide cost comparisons.
Answer:	Yes, nuclear electric propulsion can reduce launch costs. A recent tradeoff study done by the Los Alamos National Laboratory, the U.S. Air Force, Aerospace Corporation, TRW, and Aerojet Corporation showed that a 5000 pound satellite using an upper stage powered by a 30 kWe SP-100 system would reduce launch costs from one-third to one-half that of a conventional launch using a chemical rocket. This results in savings of $95 to $130 million per launch.

A nuclear electric power propulsion system could provide a high power system after orbit raising to provide power to the satellite, to provide maneuvering capability, and to increase the available mass to the spacecraft by up to thousands of pounds. For military systems these features of nuclear electric propulsion can result in substantially reduced launch costs, a hardened power system at high power, an increase in available payload mass, and provision of the power required to maneuver on orbit.

QUESTIONS FROM SENATOR MCCLURE

Question #10:	Is it really "trivial" (as asserted by D. Hirsch) to build a gun-assembly weapon from SP-100 fuel?
Answer:	No, it is not. A reactor that has operated for some time and impacted the earth would be highly radioactive. Without shielding and remote handling devices, recovery and transport of the reactor would be deadly to the people near it. Theoretically, a nuclear bomb is a deceptively simple device. Two subcritical masses are driven together into a supercritical mass that releases nuclear energy. In practice, however, building a successful high-yield bomb is a sophisticated, complex engineering feat. Depending on the interplay of many parameters, the energy released can range from a relatively minor amount to a tremendous amount. A team of highly skilled and experienced scientists, engineers, and technicians must be organized. A technology base to support the interrelated mechanical, electronic, materials, instrumentation, and nuclear specialties must be developed. Physical facilities for experiments, development and manufacturing would have to be built. Experiments with the particular SP-100 materials would have to be performed to provide additional data. Even if the facilities, staff and program were already in place, it is still estimated that many months would be required to produce a weapon from the SP-100 fuel; if facilities, etc., were not already in place, it could take years.

QUESTIONS FROM SENATOR MCCLURE

Question #11:	Why was intact reentry chosen as the preferred mode?
Answer:	Intact reentry was chosen as the preferred mode of inadvertent, but highly unlikely, reentry for SP-100 to reduce potential health and environmental effects, and to address safeguards concerns. Use of intact reentry avoids the potential for incomplete burnup of the reactor that might exist if dispersed reentry were attempted. Incomplete burnup could result in the spreading of reactor debris over an area of many square miles, thereby increasing the potential for adverse health, environmental, and safeguards consequences. Conversely, intact reentry assures confinement of the radioactive material to a minimum area, reduces the potential for adverse consequences, and facilitates location and recovery.

QUESTIONS FROM SENATOR MCCLURE

Question #12: It was asserted by both Hirsch and Aftergood that the SP-100 fuel enrichment was 97 percent. Is this really true?

Answer: This assertion is generally accurate. Specifically, the SP-100 reactor core consists of two enrichment zones, 97 percent and 89 percent U-235 enriched uranium nitride. The high enrichment is required to meet the constraints of a relatively high power, low mass system, as well as to meet long-term, high reliability requirements. A central region of 89 percent enriched fuel is used to even out the power generation and fuel burnup within the reactor core. The average enrichment of a 100 KWe reactor core is approximately 96 percent on a mass basis.

Question #13: What enrichment is necessary to achieve nuclear yield in a weapon?

Answer: It is generally recognized that enrichment above about 50 percent produces weapon-type material. Sufficient enrichment level is, however, only one of several very important factors required to successfully design and construct a nuclear weapon.

QUESTIONS FROM SENATOR MCCLURE

Question 14:	What are the consequences of a Cosmos 954 type breakup in a populated area?
Answer:	The principal consequences associated with a COSMOS 954 type breakup in a populated area would be (1) contamination of buildings and the ground; (2) risk of people contacting highly radioactive particles or debris; and (3) actual physical injuries from being struck by falling debris.

Less than 100 pieces of radioactive debris, ranging in size from a few grams to several kilograms, would be expected to reach the ground. Therefore, although a large area would be expected to be contaminated, these large pieces could be located and removed. Based on a Canadian report on COSMOS 954, the impact on the environment of unrecovered particles would likely be insignificant when compared with the fallout deposition that exists currently.

The 50 to 100 pieces of debris which would have significant radiation fields associated with them would have differing aerodynamic characteristics, which would spread out the pieces, so that no one person would likely be exposed to more than one piece. Consequences are likely to be limited to radiation burns, but could conceivably range up to a lethal

Answer 14 (continued): radiation dose, for a particularly "hot" piece and extended exposure.

Actual physical injuries from being struck by the debris would be directly related to the population density of the impact area. Although space debris reenters the earth's atmosphere daily, there has never been a recorded case of an injury resulting from such debris. The probability of such injury may be roughly compared to aircraft crashes in populated areas, which usually result in few, if any, deaths or injuries to those on the ground.

Finally, based on the COSMOS 954 cleanup, particles were found to be largely insoluble in water and in dilute acids which approximate digestive juices. Field investigations resulted in no detectable contamination of air, drinking water, soil, or food samples.

QUESTIONS FROM SENATOR MCCLURE

Question #15:	Do nuclear reactors have large characteristic signatures in space?
Answer:	Nuclear reactors can have large signatures, but steps can be taken in the design of a power source to reduce these signatures. There are two primary ways in which to detect objects in space: optical radar, which detects the cross-sectional area of the object and infrared (IR), which detects the heat of the object. The cross-sectional area of the SP-100 would not be unique or characteristic relative to other spacecraft. The IR signature could be large because of the high heat rejection temperature of the radiator. The IR signature may be masked or reduced, if required, through the use of a thermal shield. Therefore, nuclear reactors need not have large characteristic signatures in space. Furthermore, in terms of comparing the relative size of the signature of nuclear reactors to other space power sources, such as solar energy, some studies have shown that under certain conditions, nuclear reactors can be made to have less of an observable signature than solar power.

QUESTIONS FROM SENATOR MCCLURE

Question #16: What precision can be ascribed to the calculation of radiation-induced cancer deaths from reactor reentry?

Answer: Estimates of health effects from reactor reentry contained in the reports cited for Cosmos 1900 and SP-100 represent the results of risk analysis. The reported risks represent the product of probability times radiological consequences for each event leading to a radioactive release, and summed over all events. There are uncertainties inherent in any such analysis, with the reported probabilities representing a best estimate.

Specifically, there are uncertainties in the three major components of the risk analysis - the probability of occurrence of a hazardous event; the release and dispersion of the radioactive material and the exposure of individuals; and finally, the conversion of population dose to health effects, i.e., induced cancer deaths. While the uncertainties in the first two components can be reasonably estimated to within an order of magnitude, i.e., no more than a factor of 10, the third component represents a very conservative upper bound for conversion of dose to health effects. Indeed, the linkage between population dose and

Answer #16 (continued): health effects is in large part hypothetical, especially at the lower dose levels. Accordingly, although not precise, the results of any risk assessment using state-of-the-art methods can be taken to overpredict the actual likely consequences. If the "de minimus" concept (in which a dose increment less than 1 percent of natural background is deemed to have no discernible health effects) is used, the likely health effects from a widely dispersed low level dose would be zero.

QUESTIONS FROM SENATOR MCCLURE

Question 17: What orbits are "nuclear safe?"

Answer: The term "nuclear safe orbit" does not refer to a single orbit. The concept of a "nuclear safe orbit" refers to a sufficiently long-lived orbit which allows decay of the radioactive fission products to low levels before reentry could occur. The minimum operating orbit for each mission with a nuclear power system must be evaluated on a case-by-case basis with respect to the reactor operating power and lifetime. The term "nuclear safe orbit" is no longer generally used because, with the variety of user mission requirements, a single definition (such as orbit "height") is not applicable from the user perspective.

Potential U.S. space missions are designed so that once operating, the reactor will not accidentally reenter. However, as an added safety precaution, the system will be designed to accommodate accidental reentry.

QUESTIONS FROM SENATOR MCCLURE

Question 18: Does the SP-100 design under current development meet survivability requirements that potential military users require? I realize that firm requirements don't exist, but will SP-100 meet the hardness requirements proposed for advanced survivable solar power systems such as SUPER, SDIO's survivable solar power system?

Answer: Little detailed design work has been done so far under the SP-100 program that would confirm that the specific design features are able to meet hardness requirements, since the focus of this program is on a ground engineering system test. However, analysis suggests that nuclear systems can meet the hardness requirements for the SUPER program. Compared to solar power systems, nuclear power systems have inherent hardenability characteristics with the potential to be 10 times harder than hardened solar to the nuclear weapons threat and 2 times harder to the laser threat. In the case of system generated electromagnetic pulse, both solar and nuclear power systems can survive the threat levels, but in the case of solar, this is a much more stressing problem and will involve significant weight penalties to shield exposed cables. The threat to any power system from kinetic energy weapons is essentially determined by comparing the exposed surface area for each system. Thus, for a 30 kWe system, an SP-100 would be from 14 to 34 times less vulnerable to the kinetic energy weapon threat than a solar power system.

QUESTIONS FROM SENATOR MCCLURE

Question #19:	Are there technologies for nuclear space power systems other than the thermoelectric system being pursued in SP-100? What programs do you have for development of other technologies?
Answer:	Energy conversion technologies for nuclear space power systems other than thermoelectrics are being pursued. For example, in-core thermionic fuel elements are being tested under the DOE Multimegawatt Space Power program because of the potential of thermionics for application to higher power requirements. DOE also has in place a program to develop a closed Brayton cycle dynamic power conversion system that could be used with the SP-100 reactor. Other nuclear space power system technologies applicable in this power range include Stirling engine power conversion, and out-of-core thermionic power conversion. The free piston Stirling engine is being developed by NASA as part of the SP-100 Advanced Aerospace Technology effort.

Department of Energy
Washington, DC 20585

December 9, 1988

Honorable J. Bennett Johnston
Chairman, Committee on
Energy and Natural Resources
United States Senate
Washington, D.C. 20510

Dear Mr. Chairman:

Following the hearing on September 13, 1988 on "Cosmos 1900 and the Future of Space Nuclear Power", the Committee sent a number of written questions to the Department of Energy's witness, Mr. Dennis A. Bitz, Deputy Assistant Secretary for Space and Defense Power Systems. The Department is pleased to have had the opportunity to participate in this hearing, and we have now sent our answers to your questions back to the Committee under separate cover.

During the hearing several assertions were made by non-government witnesses with regard to government-sponsored space nuclear power development programs, particularly concerning their safety and performance. Many of these statements were at variance with the history, motivations and safety approach for the use of nuclear power in space as understood by the government agencies responsible for developing this technology. Therefore, we would like to take this opportunity to submit additional information for the record in response to those assertions. Enclosed are brief statements of the assertions followed by comments on their accuracy and of the assumptions behind them. We believe this material will clarify some of the remarks made during the hearing by both the government and the non-government witnesses, and respectfully request that it be included in the record of the hearing.

If we can provide any additional information or clarification, we would be pleased to do so.

Sincerely,

for Delbert F. Bunch
Principal Deputy Assistant Secretary
for Nuclear Energy

Enclosures

cc: Honorable James McClure
Ranking Minority Member

Additional Information Provided for The Record By The Department of Energy

During the hearing several assertions were made by non-government witnesses with regard to government-sponsored space nuclear power development programs, particularly concerning their safety and performance. Many of these statements were at variance with the history, motivations and safety approach for the use of nuclear power in space as understood by the government agencies responsible for developing this technology. A summary of the most significant assertions and comments thereon follows:

Assertion: The 1964 burnup in the atmosphere of the SNAP-9A RTG, the first nuclear power accident in space, resulted in a tripling of the worldwide inventory of Pu-238.

Comment: This statement is misleading because the event was not a nuclear power accident, but a mission abort due to failure of the rocket to insert the payload into orbit. The nuclear safety systems functioned as designed. The statement is further misleading in that Pu-238 represents only a small fraction of the total world environmental burden of plutonium. Therefore, the increase in Pu-238 was relatively small compared to the total amount of plutonium in the environment prior to the burnup of SNAP-9A. Pu-238 contributed approximately 2 percent to the total world environmental burden of plutonium (from weapons testing fallout) before the accident. The dispersal of Pu-238 from SNAP-9A increased that percentage to 6 percent--only a 4 percent increase in overall plutonium inventory.

Assertion: SNAP-9A was 50 times more consequential than either of the two Soviet Cosmos reactors that have reentered to date.

Comment: This statement is very misleading. None of these events, Cosmos 954 or 1402 or SNAP-9A, have been shown to have had any health consequences. Also, the nature of the release from SNAP-9A, a radioisotope thermoelectric generator, was different than that from the Soviet reactors. SNAP-9A contained plutonium-238, whereas Cosmos 954 and 1402 released reactor fission products. Finally, it should be noted that SNAP-9A functioned exactly as intended in the event of failure to achieve orbit, i.e., the radioactive material was dispersed and burned up in the atmosphere, in accordance with the nuclear safety philosophy in effect at that time.

Assertion: Cosmos 1900 reentry will cause up to 200 deaths.

Comment: Estimates provided by Mr. Hirsch and Mr. Aftergood are unrealistically high. The earlier DOE contractor estimates which they referred to from 1979 were based on very preliminary information and models. A recent analysis using the more accurate models that are available today is presented in the report, "A Pre-Boost Risk Assessment of Cosmos 1900" that has been provided for the record. This report shows that the radiological risk of Cosmos 1900 is substantially less than that suggested by Messrs. Hirsch and Aftergood.

Assertion: There is a lack of openness and public accountability in the U.S. space nuclear power program.

Comment: Mr. Aftergood's comments about the openness of the U.S. space nuclear power program ignore the facts that open project review meetings are held annually on the SP-100 Program, and that Mr. Aftergood has attended most of these. He has also been permitted to attend closed meetings intended only for project personnel. In addition, the SP-100 program publishes a quarterly newsletter and makes various brochures and reports available under a public information program. It also sponsors an annual symposium open to the public, and submits semi-annual reports to the Congress. Finally, safety-related information pertaining to SP-100 is unclassified and available to the public.

Assertion: The SNAP-10A reactor failed after only 43 days of operation.

Comment: The SNAP 10A reactor system did not fail as claimed by Mr. Hirsch. After 43 days of operation, it was permanently shut down as designed due to a malfunction in the spacecraft electronics.

Assertion: Power excursions, anti-satellite weapons or impacts with space debris may cause reactor accidents.

Comment: Space reactors are designed to preclude a reactivity insertion rate which would lead to a power excursion; it is therefore not possible to have a reactor excursion fragment the core. Two space reactors were destructively tested in the 1960's, one in Idaho and one in Nevada. The objective of the Idaho test was to determine the reactor's response to water immersion. Obviously, water immersion cannot initiate a power excursion in space. To cause the reactor excursion in Nevada, the control drives were modified to increase the reactivity insertion rate sufficiently to disrupt the core.

Debris hits and ASATs would represent similar damage mechanisms against an SP-100 reactor. Since the core is very dense and much heavier than any debris or projectile, only vessel penetration with fuel rod damage not exceeding 10 percent would be anticipated. Each fuel rod is separately encapsulated, so most fission products would not be released.

Finally, even if the reactor were fragmented, the fuel rods, fuel pellets, or the core itself would have ballistic coefficients much greater than the intact power system (contrary to Mr. Hirsch's assertion), and would therefore have longer orbital lifetimes than the intact system. Vapor and small particles which would be generated would take 3 to 10 years to reach the surface of the earth, by which time substantial decay of the radioactive fission products would have taken place.

Assertion: Ten percent of the SDIO budget has been spent on nuclear explosive-pulsed systems or nuclear reactor power systems.

Comment: Less than 1 percent of the FY 1988 SDIO budget was used to support the development of space nuclear power systems such as the SP-100 program.

Assertion: Almost all of the direction of the SP-100 and related programs is coming from SDIO.

Comment: Direction of the SP-100 Program is provided by a Steering Group with representatives from three agencies, SDIO, NASA, and the Department of Energy. DOE has the primary responsibility for overall program management with project management provided by the Jet Propulsion Laboratory and the Los Alamos National Laboratory.

Also, the design of a system for a civilian mission for scientific purposes is not substantially different from the design for military missions for surveillance or weapons platforms. The only substantial difference is the spacecraft survivability requirements. Meeting survivability requirements does not cause a redesign of the system, but rather an increase in the hardness of the 'basic' system. The same reactor designed for civilian missions is applicable to military missions and vice-versa.

Assertion: About 15 percent of our space nuclear power missions has suffered one form of failure or another, about the same percentage as the Soviets.

Comment: Since 1961 the U.S. has launched over 30 radioisotope thermoelectric generators and one reactor. All but a few of these successfully achieved orbit and operated as planned. In those cases where the missions were not successful, the nuclear power sources were not the cause of the mission failures, which have been primarily due to causes such as failure of a rocket to boost the nuclear power source into orbit. All U.S. nuclear power sources have performed as designed.

Viewed from the aspect of design safety features, the performance of space nuclear power sources has been very successful. To date, no health consequences have been identified from any of the described incidents.

NUS-5148

A PRE-BOOST RISK ASSESSMENT OF COSMOS 1900

Prepared for

Office of Special Applications
U.S. Department of Energy

October 17, 1988

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Contract No. DE-AC01-87NE32134

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1.0 INTRODUCTION

The Soviet Union has been launching nuclear reactor powered satellites since 1967. The nuclear reactors used on these satellites are in the 5-10 kWe range, fueled by highly enriched U-235. The typical mission profile following launch consists of deploying the satellite in a low orbit (approximately 250 km) with an orbital inclination of 65 degrees and an operational lifetime of 2 to 4 months. Following operation in the low earth orbit, the satellite is reboosted to a long-lived orbit (approximately 950 km high). Approximately 30 such satellites, with COSMOS mission number designations, have been launched by the Soviet Union since 1967. In earlier missions, COSMOS 954 and COSMOS 1402 failed to reboost into a high orbit and subsequently reentered the earth's atmosphere. COSMOS 954 reentered over northern Canada on January 24, 1978, with approximately 80 percent burning up at high altitude and 20 percent reentering in pieces. COSMOS 1402 separated into system parts prior to reentry, with the reactor structural component reentering on January 23, 1983 over the Indian Ocean, and the reactor fuel core reentering on February 7, 1983 over the South Atlantic. The COSMOS 1402 reactor core is believed to have burned up upon reentry. On December 12, 1987 the Soviet Union launched COSMOS 1900, another nuclear-powered satellite. In April 1988 the Soviet Union lost communications with COSMOS 1900 in the low orbit, and there was concern that it may reenter the earth's atmosphere and pose a radiological hazard. Fortunately, safety systems onboard COSMOS 1900 operated automatically, and reboosted the nuclear reactor to a high orbit on October 1, 1988.

At the request of the U.S Department of Energy (DOE), NUS Corporation has prepared this report presenting a risk assessment of the reentry of COSMOS 1900, addressing postulated scenarios in which the safety systems do not operate as planned. The focus of this report is on the pre-boost radiological risk posed by the COSMOS 1900. However, associated debris hazards posed to humans and air traffic are also addressed. This work was performed under DOE Contract No. DE-AC01-87NE32134.

The Organization of this report is as follows:

Section 2.0	Presents the summary and conclusions of the report
Section 3.0	Presents reference design information and assumptions related to the mission profile and nuclear reactor supporting the risk analysis. Defines a range of accident scenarios reflecting partial or total reentry burnup cases. Presents estimated COSMOS 1900 radionuclide inventories and source terms corresponding to the operating shutdown times.
Section 4.0	Presents the risk analysis and results in terms of radiological risks, debris hazards, and hazards to aircraft.
Section 5.0	Presents a risk comparison of COSMOS 1900 with SNAP 9A, COSMOS 954, COSMOS 1402, and background radiation levels.
Section 6.0	References supporting the study.

2.0 SUMMARY AND CONCLUSIONS

This section summarizes the results of this study in terms of the radiological risk, debris risk, hazard to aircraft due to COSMOS 1900 prior to its successful reboost to a high orbit.

2.1 ACCIDENT SCENARIOS

Based on information provided in Reference 1, the following profile and accident scenarios are assumed for COSMOS 1900 for the purpose of this risk analysis:

1. The nuclear reactor operating period at full power is from December 12, 1987 to October 1, 1988.
2. On October 1, 1988 (time T) loss of attitude control is assumed, leading to activation of the safety systems. If reactor safety systems include provisions for shutdown when loss of altitude control is detected, separation of the kick stage with the nuclear reactor and reboost to the high orbit would be automatically attempted. The radar antenna and launcher second stage would promptly burnup upon reentry. Failing reboost, the second safety system would eject the core in the low orbit in a manner similar to COSMOS 1402. Sequence of events would then include prompt reentry burnup of the radar antenna at T + 2 days; reentry burnup of the launcher second stage and kick stage on T + 26 days; and the reentry of the ejected core at T + 41 days. Failure of all safety systems would lead to prompt reentry at time T, with partial reentry burnup as in COSMOS 954.

From a reliability viewpoint, the following assumptions are made:

1. Case 1: The probability of first safety system operating successfully resulting in reboost is 0.45.
2. Case 2: The probability of first safety system failing and second safety system ejecting core successfully as in COSMOS 1402 is 0.45.
3. Case 3: The probability that both safety systems fail with no reactor shutdowns, resulting in prompt reentry and partial burnup, as in COSMOS 954, is 0.1.

2.2 Radiological Risk

A radiological consequence analysis was performed for the above three cases as described in Section 2.1. The results were initially developed in parametric equation form for each case, so that if COSMOS 1900 would have reentered, the radiological consequences could have been calculated based on actual reentry conditions. Numerical results were also determined for estimated parameter values. The resulting radiological consequences for Cases 1, 2, and 3 were 5.15×10^{-3}, 4.76×10^{-2}, and 1.82×10^{-1} excess cancer fatalities, respectively, assuming a random reentry and a health effects estimator of 120 excess cancer fatalities per million person-rem.

Defining risk as the product of probability and consequences for each case, and summed over all cases, the pre-boost radiological risk is estimated to be 4.19×10^{-2}

excess cancer fatalities. Due to the successful reboost of COSMOS 1900 to the high orbit, the radiological consequences of COSMOS 1900 is estimated to be 5.15×10^{-3} excess cancer fatalities, corresponding to Case 1 with a probability of 1.0.

2.3 DEBRIS RISKS

The above risk analysis is based on a uniform population density, and does not address individuals approaching or picking up debris and fuel particles in the case of a partial reentry burnup, as in Case 3. Should COSMOS 1900 have had a partial burnup reentry as COSMOS 954 it is estimated there may have been 50 to 100 pieces of debris, not including fuel, with significant radiation fields associated with them (100 to 200 R/hr within 5 inches). In addition, fuel particles on the order of 100 to 1000 microns in diameter would have been scattered across a footprint with an approximate area of 50,000 km^2.

Exposure to reactor structural materials, and possibly reactor fuel particles could deliver possibly significant direct doses to individuals due to short term inadvertent exposure. These doses could range from those adequate to cause skin burns to much higher levels, depending on the length of the exposure and the strength of the radiation field involved. The number of people involved would be strongly dependent on population density and communication capability.

According to the Soviet Union, the problem of neutron activated components that survived reentry with COSMOS 954 would not have occurred with COSMOS 1900 due to a redesign. Therefore, the debris risks described above may be overstated.

2.4 AIRCRAFT HAZARDS

The probability of any debris (other then small particles) from a partial reentry burnup of COSMOS 1900, as in COSMOS 954 (Case 3), to aircraft operating within the debris footprint following reentry is estimated to be less than 2×10^{-10} per aircraft. This hazard is considered negligible. Furthermore, accumulation of small particulate fallout on aircraft surfaces is also estimated to be negligible.

2.5 RISK COMPARISON

The radiological risk of COSMOS 1900 has been compared to other previously reentered nuclear systems, including SNAP-9A, COSMOS 954, and COSMOS 1402. The total risks of these four systems were estimated to be 5.43×10^4 person-rem (6.52 excess cancer fatalities). The combined population dose risk of these systems is estimated to be 0.011 percent of the annual population dose due to natural background radiation. This assumes that the population dose risk of these systems accumulated in a single year. In reality, the population dose risk would accumulate over a period of years, so the percentage of background radiation would be far less than reported.

The radioactivity estimated released from the reentry of COSMOS 954, 1402, and 1900 (following reentry from long-lived orbit) combined represented 0.00096 percent of that due to global fallout from prior nuclear weapon testing.

3.0 REFERENCE DESIGN INFORMATION

This section presents reference design information and assumptions related to the COSMOS 1900 mission profile and nuclear reactor needed in support of the risk analysis.

3.1 MISSION REFERENCE DESIGN

After the COSMOS 954 partial burn-up reentry in 1978, the Soviet Union implemented some design changes and modified operational procedures to ensure high reliability burnup reentry should a failure to reboost from low orbit occur.

The new proper sequence of operations and events were displayed by the successful mission of COSMOS 1266, described in Reference 1. At the end of its operative life in the low orbit, the spacecraft separated into three parts: the launcher-expended second stage (object 1) and the large radar antenna (object 2) reentered the atmosphere and burned-up; and the third section (object 3), containing the nuclear reactor and a small kick stage, boosted the nuclear reactor into the high, long-lived orbit. The nuclear core (object 4) was then ejected from the reactor structural component to ensure reentry burnup after approximately 500 years.

A failure of the proper operational sequence of the redesign was demonstrated by COSMOS 1402 (Reference 1). At the end of its mission on December 28, 1982, COSMOS 1402 ejected the radar antenna successfully, but the kick stage failed to separate, preventing the boost of the nuclear reactor into the high orbit. The Soviet Union then commanded ejection of the reactor core to ensure reentry burnup. Due to the large cross-section to mass ratio (low ballistic coefficient or W/C_DA) the radar antenna's orbit decayed very quickly, and reentered the atmosphere on December 30, 1982. The launcher second stage with the kick stage still attached, reentered on January 23, 1983 over the Indian Ocean. The reactor core reentered on February 7, 1983 over the southern Atlantic Ocean, and is presumed to have burned up.

COSMOS 1900 was launched and deployed into the low orbit on December 12, 1987. Subsequently, the Soviet Union lost communications with COSMOS 1900 and could not effect reboost to higher orbit by ground command. The following design features are noted:

1. COSMOS 1900 has two autonomous safety systems. The first safety system will separate the reactor part of the spacecraft and boost it into a higher orbit if any anomalies are detected. These anomalies would include a temperature rise in the core or a shutdown of the reactor. If there is a failure to reboost the reactor, the second safety system will come into play as in COSMOS 1402 and eject the reactor core. Reentry burnup of the reactor core would follow.

2. The problem of neutron-activated components that survived reentry with COSMOS 954 will not occur because of a redesign. COSMOS 1402 was of this new design and, according to the Soviet Union, the components burned up. COSMOS 1900 is essentially the same design as COSMOS 1402 (with some minor differences).

Based on the above information, the following profile and accident scenarios are assumed for COSMOS 1900 for the purpose of this risk analysis:

1. The nuclear reactor operating period at full power is from December 12, 1987 to October 1, 1988.

2. On October 1, 1988 (time T) loss of attitude control is assumed, leading to activation of the safety systems. If reactor safety systems include provisions for shutdown when loss of attitude control is detected, separation of the kick stage with the nuclear reactor and reboost to the high orbit would be automatically attempted. The radar antenna and launcher second stage would promptly burnup upon reentry and no radiological hazard would be posed. Failing reboost, the second safety system would eject the core in the low orbit in a manner similar to COSMOS 1402. Sequence of events would then include prompt reentry burnup of the radar antenna at T + 2 days; reentry burnup of the launcher second stage and kick stage at T + 26 days; and the reentry of the ejected core at time T + 41 days. Failure of all safety systems would lead to prompt reentry at time T, with partial reentry burnup as in COSMOS 954.

From a reliability viewpoint, the following assumptions are made:

1. The probability of first safety system operating successfully resulting in reboost is 0.45.

2. The probability of first safety system failing and second safety system ejecting core successfully as in COSMOS 1402 is 0.45.

3. The probability that both safety systems fail with no reactor shutdown, resulting in prompt reentry and partial burnup as in COSMOS 954, is 0.1.

3.2 NUCLEAR REACTOR DESIGN

The nuclear reactor on COSMOS 1900 is assumed to be a fast- neutron spectrum reactor with a full power output of 75 kilowatts thermal (kwt). According to information provided by the Soviet Union to the International Atomic Energy Agency, a uranium-molybdenum (3 weight percent) alloy 90 percent enriched in uranium-235 is used as nuclear fuel (total weight 31.1 kg). Other details of reactor design, such as cooling, neutron shielding, control drums, and power conversion do not affect the risk analysis except from the viewpoint of the nature of debris that may survive reentry heating. The cases addressed in this report, as described in Section 2.2, include total reentry burnup as in COSMOS 1402 (0.45 probability) or partial burnup as in COSMOS 954 (0.1 probability). In the later case the characteristics of COSMOS 954 debris are referenced. Accordingly, the risk analysis is not sensitive to other details of reactor design. Therefore, they are not addressed further.

The radionuclide inventory at the time of reentry was calculated with the ORIGEN code (Reference 2) for each case considered based on the power-level (75 kwt), the operating period, the shutdown period prior to shutdown.

The reactor operating and shutdown periods, and the fuel release fractions assumed for each case are summarized in Table 3-1. The resulting radionuclide inventories are presented in Appendix A.

Table 3-1
Reactor Operating Parameters and Release Fractions

Case	Reactor Operating Period	Shutdown Period Prior to Renetry	Release Fraction
1	293 days	500 years	100% Vapor at High Altitude
2	293 days	41 years	100% Vapor at High Altitude
3	293 days	-	80% Vapor at High Altitude 20% Debris[a]

[a] Based on COSMOS 954 breakup described in Reference 3.

4.0 RISK ANALYSIS AND RESULTS

This section presents the risk analysis and results in terms of radiological risks (Section 4.1), debris hazards (Section 4.2), and hazards to aircraft (Section 4.3).

4.1 RADIOLOGICAL RISK

The radiological consequences of the accident scenarios and associated source terms defined in Section 3.0 have been evaluated using the methods described in Appendix B, based on the information and models presented in References 4 and 5. The population exposure pathways considered include all those resulting in inhalation, ingestion, and external exposure to released radioactivity. The risk of Cases 1, 2, and 3 (see Section 3.2) is defined as the case probability times the case consequences, characterized by excess cancer fatalities.

The radiological consequences of Cases 1, 2, and 3 (see Section 3.0 and Table 3-1) will be functions of the reentry latitude and longitude, which in turn define earth surface types (land or ocean) and the population density affected. A random reentry from an orbit with an inclination of 65 degrees is assumed.

In Case 1, COSMOS 1900 has a successful reboost to a long-lived orbit followed by core ejection. Orbital decay is estimated to occur at T+500 years, where T is the time of reboost. Complete reentry burnup is assumed, with only long-lived radionuclides contributing to the radiological consequences. The material released at high altitude will filter down over a period of years, resulting in normalized air concentration varying with time following burnup as shown in Figure 4-1 for various release altitudes (Reference 5). The latitudinal distribution of material will be a function of reentry latitude, as shown in Figure 4-2 from Reference 4. The radiological consequences are estimated to be given by the following parametric equation:

$$H_1 = 5.15 x 10^{-3} r_i \tag{1}$$

where:

H_1 = *Health effects, excess cancer fatalities (Case 1)*

r_i = *Risk index as a function of reentry latitude i, from Figure 4-3 (Reference 5)*

Assuming an expectation reentry latitude of a 0 degrees, $r_i = 1$ and $H_1 = 5.15 \text{ x} 10^{-3}$ excess cancer fatalities. This calculation assumes a health effects estimator of 120 excess cancer fatalities per million person-rem.

In Case 2, COSMOS 1900 fails to reboost but successfully ejects the core. Complete reentry burnup of the core is assumed at T+41 days, where T is the time of reactor shutdown. The radiological consequences are given by the following parametric equation:

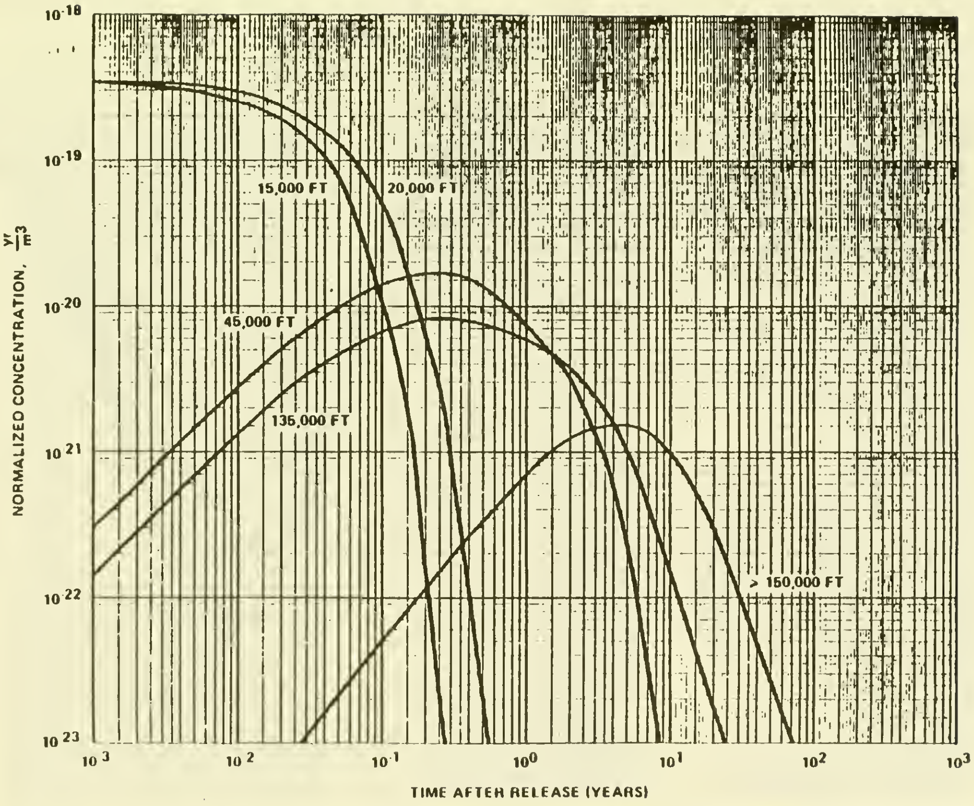

Figure 4-1 Ground-Level Normalized Airborne Concentrations for High Altitude Vapor Releases

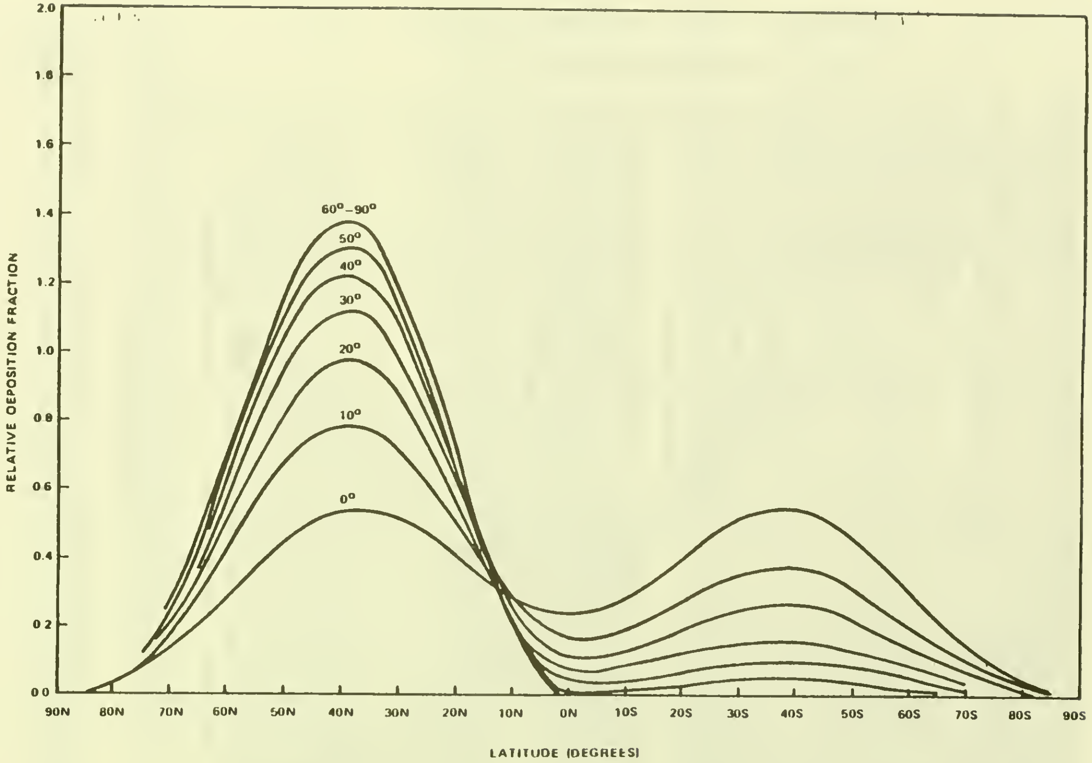

Figure 4-2 Deposition of Vapor Released at High Altitude as a Function of Reentry Latitude

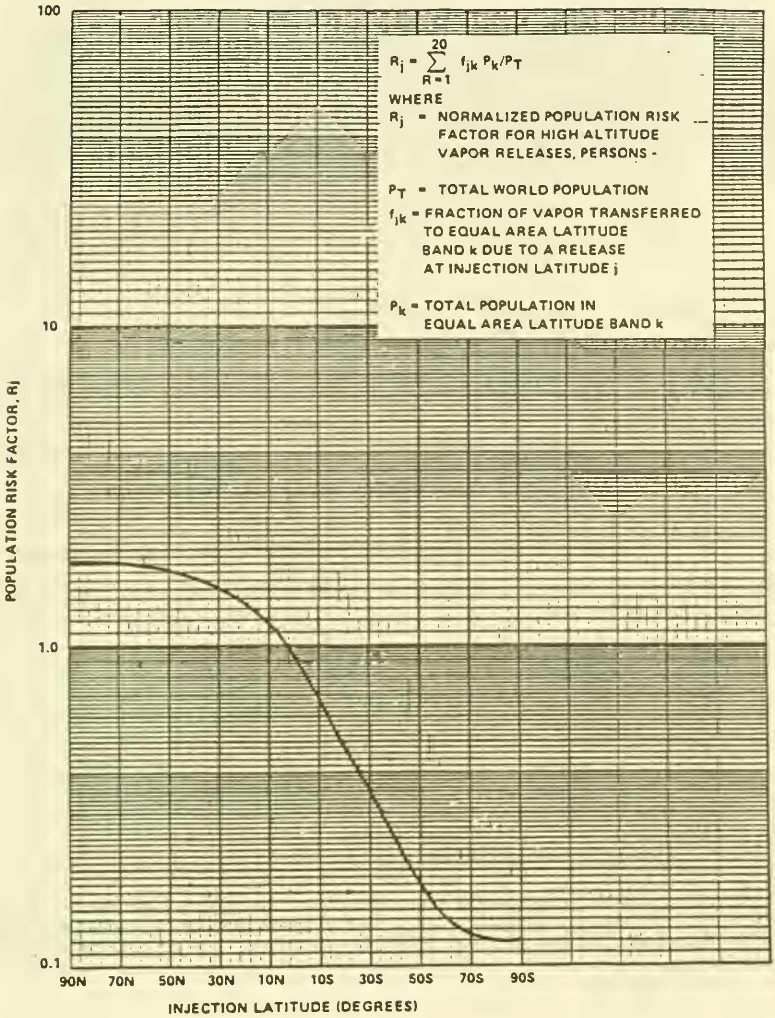

Figure 4-3 Normalized Population Risk Factor as a Function of Reentry Latitude for High Altitude Vapor Releases

$$H_2 = 4.76 \times 10^{-2} r_i$$

Assuming $r_i = 1.0$ as before, then $H_2 = 4.76 \times 10^{-2}$ excess cancer fatalities.

In Case 3, COSMOS 1900 fails to reboost, fails to eject the core, and a COSMOS 954 type partial reentry burnup occurs. No reactor shutdown is assumed prior to reentry. The radiological consequences are given by the following parametric equation:

$$H_3 = 4.68 \times 10^{-2} r_i f_1 + 9.20 \times 10^{-2} F_1 f_2 \rho + 1.94 \times 10^{-2} \tag{2}$$

where:

f_1 = *Fraction of fuel vaporized, from Tables 3-1*

f_2 = *Fraction of fuel that promptly falls out as particulates or debris, from Table 3-1*

F_1 = *Fraction of footprint area on land, from Figure 4-4 (Reference 4)*

F_2 = *Fraction of footprint area on shallow ocean, from Figure 4-4 (Reference 4)*

ρ = *Population density, persons/km^2, from Figure 4-5 (Reference 4)*

The parameters of interest, based on a 65 degree orbital inclination and a random reentry, are as follows:

r_i = 1.0

f_1 = 0.8

f_2 = 0.2

F_1 = 0.29

F_2 = 0.042

ρ = 27 *persons/km^2*

The result for Case 3 is $H_3 = 1.82 \times 10^{-1}$ excess cancer fatalities. This result assumes a uniform population distribution and does not account for individuals closely approaching and, possibly, picking up radioactive debris. The latter is addressed in Section 4.2.

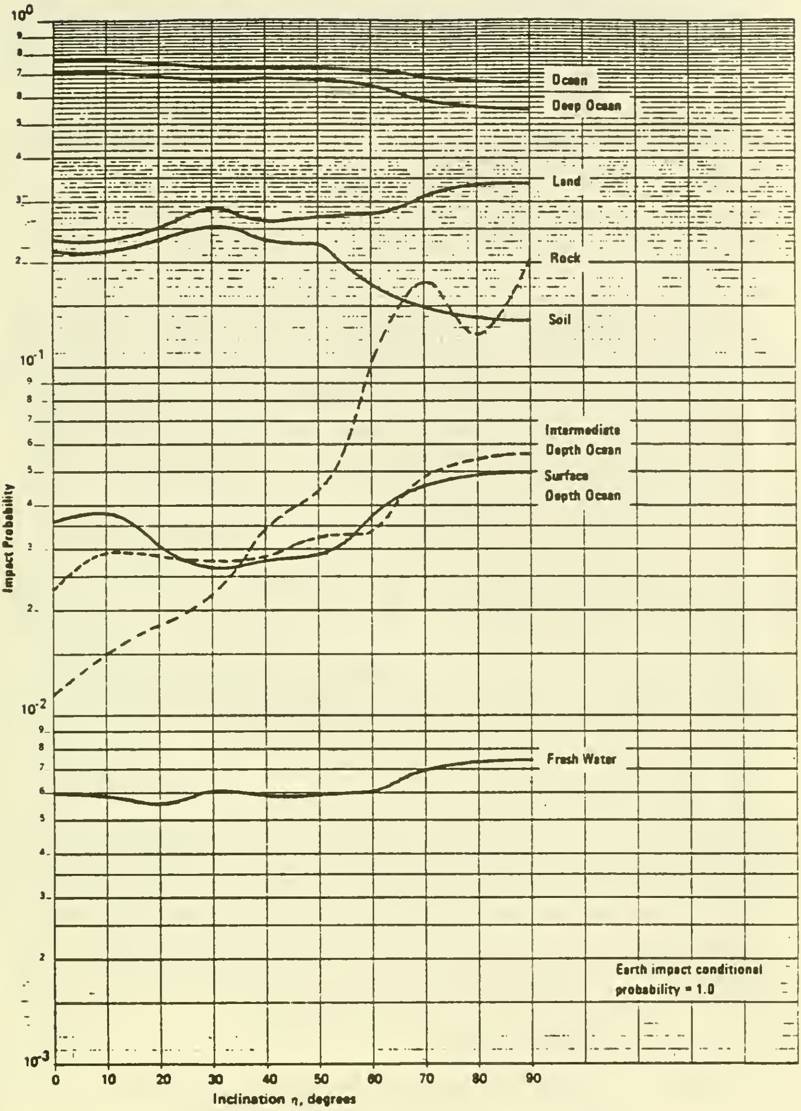

Figure 4-4 Random Orbital Reentry Impact Probabilities

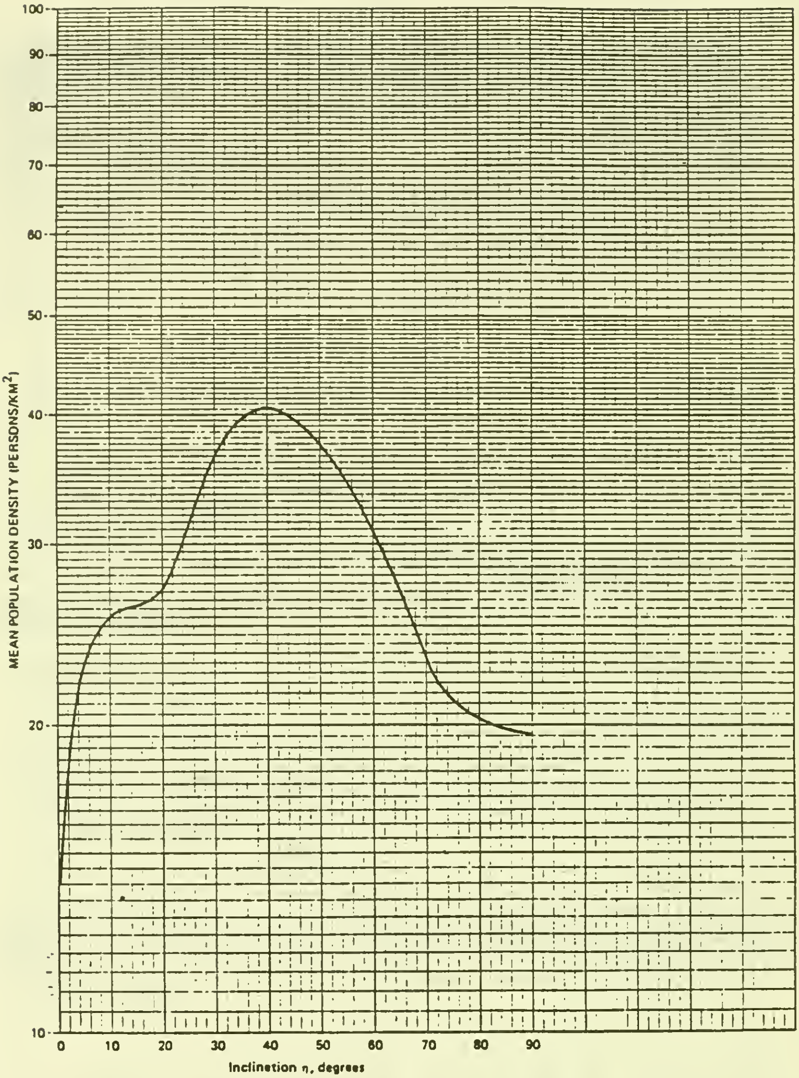

Figure 4-5 Expected Population Density Impacted from Random Reentry as a Function of Orbital Inclination

The radiological risk of COSMOS 1900 reentry is defined as the probability times the radiological consequences of each case, and summed over all cases considered. That is,

$$R = \sum_{j} P_j H_j \tag{3}$$

where:

R = *Radiological risk of COSMOS 1900, expectation of excess cancer fatalities*

P_j = *Probability of Case j*

H_j = *Radiological consequences of Case j, excess cancer fatalities*

Based on the previous results, the radiological risk of COSMOS 1900 is estimated to be:

$$R = 0.45\,(5.15 \times 10^{-3}) + 0.45\,(4.76 \times 10^{-2}) + 0.1\,(1.82 \times 10^{-1})\ nce$$

$$= 4.19 \times 10^{-2}\ \textit{expectation of excess cancer fatalities}$$

Due to the successful reboost of COSMOS 1900 to the high orbit, corresponding to Case 1 with a probability of 1.0, the present estimated risk is 5.15×10^{-3} excess cancer fatalities.

The radiological risk analysis presented above assumed a linear dose response model, with a portion of the calculated health effects resulting from low doses to large numbers of persons. If one accepts the concept of de minimis, a dose level below which health effects would not be calculated, then the risk would be less than that reported above.

4.2 DEBRIS RISK

The risk analysis results reported in Section 4.1 deal with radiological consequences based on models of atmospheric transport and dispersion of radioactive releases resulting from reentry and burn-up. The information below addresses the possibility of radiation doses to individuals resulting from exposure to discrete pieces of COSMOS 1900 which could survive reentry to earth impact, as in Case 3.

The recovery operations for the COSMOS 954 reentry over northern Canada were documented in References 3, 6, and 7. There were several categories of identifiable reactor debris having measurable radiation fields associated with them, as follows:

Piece	Radiation Field
Metal (stainless steel)	200 R/hr at 5 inches
Beryllium Rods	2-100 R/hr on contact
Reactor Fuel Particles	10-100 mR/hr at 1M (up to 500 R/hr on contact)

The reentry footprint for COSMOS 954 was over northern Canada. It is speculated that the reactor neutron shield protected the reactor and reactor structure during reentry, resulting in the survival to the earth's surface of the listed debris. With the design improvements described in Section 3.1 upper atmospheric burnup of reactor fuel would be expected to be enhanced (over that experienced by COSMOS 954). Assuming that the reentry is such that the reactor components survive reentry, then there are two bounding cases to consider:

1. A COSMOS 954 reentry type (if core separation fails)
2. Reentry of reactor structure (excluding the reactor fuel) as per COSMOS 954 and separate high altitude burnup of reactor fuel.

The only difference in these cases is the presence or absence of a fuel particle footprint.

If the reentry is over ocean, as was COSMOS 1402, then reentered material surviving to the surface will sink in the ocean and essentially have no public health impact. However, if reentry is over land, then the consequences will be affected by the specific location. Factors which are important are population density and accessibility to recovery teams and public information. For example, the northern Canada reentry had minimal effects since the population density in the footprint area was very low.

Radioactive debris can have public health effects in a scenario which can be described wherein pieces might be picked up from the ground and retained as items of curiosity until warned by public information broadcasts or recovery workers. This time interval could range from less than one day in the developed countries to several days or weeks in parts of the third world.

It is estimated that there may be 50 to 100 pieces of debris (not including fuel) with significant radiation fields associated with them. Because of differing aerodynamic characteristics, these pieces will be spread out significantly, so no one person is likely to be exposed to more than one piece. Consequences are likely to be limited to radiation burns, but could conceivably range up to a lethal radiation dose for a particularly "hot" piece and extended exposure.

In the case of a footprint of reactor fuel particles, it is not likely that they would be identifiable as items of curiosity and picked-up. Rather, individual particles might be caught-up in clothing, resulting in short term hot-spot irradiation of a part of the body. These particles will be much more widespread than reactor structural debris and they may be impractical to completely clean-up.

In summary, exposure to reactor structural materials, and possibly reactor fuel particles, similar to those resulting from COSMOS 954 could be expected to deliver possibly significant direct radiation doses to individuals due to short term inadvertent exposure. These doses could range from those adequate to cause skin burns to much higher levels, depending of the length of exposure and the strength of the radiation field involved. The number of people involved would be strongly dependent on population density and communication capability.

It is important to note that the above discussion related to debris assumes a COSMOS 954 type reentry. Information provided by the Soviet Union indicates that the problem of neutron-activated components that survived reentry with COSMOS 954 would not have occurred with COSMOS 1900 due to a redesign.

4.3 AIRCRAFT HAZARDS

This section summarizes information related to potential effects that COSMOS 1900 reentry may have on air traffic.

In evaluating the effects that COSMOS 1900 might have had on operating aircraft, consideration must be given to the probability that any given aircraft would have been operating within the footprint area at the time of reentry. Any aircraft operating further north than 65°N. latitude or further south than 65°S. latitude would not encounter any hazard. For aircraft operating between these two latitudes, the probability that any given aircraft would have been operating within the footprint at the time of reentry is approximately 10^{-4}, representing the ratio of the footprint area to the area between the two latitude bands. In this case the footprint area is estimated to be 50,000 km^2, assuming a Case 3 -type partial reentry burnup (References 3, 6, and 7). The probabilities that the footprint is over land or water are 0.29 and 0.71, respectively, based on Figure 4-4.

The total cross-sectional area of 57 large pieces associated with COSMOS 954 was 0.68 m^2. The cross-sectional area of a Boeing 747 is approximately 1×10^3 m^2. Since the aircraft cross-sectional area is much larger than that of the large pieces, the probability that any given aircraft of this type within the footprint area would be hit by one of the larger pieces is approximately 2×10^{-5}, representing the ratio of the aircraft cross-sectional area to the footprint area. Therefore, the total probability of any large aircraft between the 65° latitude band limits being hit by a large piece is approximately 2×10^{-9}. However, since COSMOS 1900 has a more reliable burnup design than COSMOS 954, a reduced hit probability would be expected. Assuming a factor of 10 reduction, the hit probability per aircraft becomes 2×10^{-10}.

Next consider the hazard to aircraft associated with the vaporized fuel remaining at high altitude. Such vaporized fuel will be dispersed worldwide and will require several years before it reaches ground level. To put this in perspective, the total radioactivity that would be released in vapor form at high altitude has been compared to that released as a result of weapons testing in the upper atmosphere, using Sr-90 as a reference. If COSMOS 1900 behaved in a manner similar to that of COSMOS 954, the ratio of the released Sr-90 to that initially due to weapons testing is approximately 10^{-6} based on Reference 11.

Any fuel particles that are in the size range of 100 to 1000 microns are expected to promptly fallout within the footprint area. The maximum instantaneous Sr-90 air concentration due to these particulates is estimated to be 2×10^{-9} μCi/ml and the corresponding average concentration over the entire footprint is estimated to be 2×10^{-13} μCi/ml. Should any outside air be ingested by the aircraft air conditioning and pressurization systems, the interior airborne concentrations would not exceed these values, and would probably be significantly less. These Sr-90 air concentrations can be compared to the maximum permissible concentration limit for Sr-90 established by NRC for releases to unrestricted areas which is 3×10^{-11} μCi/m. The maximum Sr-90 ground concentration is estimated to be 1 μCi/m^2, with an average ground concentration over the entire footprint of 8×10^{-5} μCi/m^2.

The fallout particulates would result in the contamination of the upper surfaces of aircraft parked in the footprint area. These surface concentrations are expected to be approximately the same as the ground concentrations discussed above. Aircraft flying through the footprint area immediately following the time of reentry and for several days thereafter would pick up additional contamination, with the front profile of the aircraft acting as a filter. It is assumed that the footprint is approximately 50 km wide and 1,000 km long. It is estimated that an aircraft flying on a course that traversed the area during the peak deposition period would have a resulting surface contamination on its frontal surfaces of 2×10^{-4} L μCi/m^2 where L is the distance traversed in kilometers.

The above hazards to aircraft and the resulting risk are considered negligible.

5.0 RISK COMPARISON WITH OTHER REENTERED SYSTEMS

This section summarizes a comparative risk assessment of SNAP- 9A, COSMOS 954, and COSMOS 1402, and COSMOS 1900. This assessment has been prepared based on reference design information for each system along with methodology described in Appendix B and the results presented in Section 4.0.

5.1 SNAP-9A

On April 21, 1964, a Transit navigational satellite was launched with a Thor Able Star rocket from Vandenberg Air Force Base, California. The payload included a SNAP-9A Radioisotope Thermoelectric Generator (RTG) containing 17,000 Ci of Pu-238. The system failed to achieve orbit and reentered the atmosphere over the island of Madagascar in the Indian Ocean at approximately 11° S. latitude and 40° E. longitude. On reentry, the RTG burned up at an altitude of approximately 150,000 feet, resulting in complete vaporization of the Pu-238 fuel (References 9 and 10).

Worldwide measurements of Pu-238 concentrations in air and soil indicated that by 1971 approximately 80 percent of the SNAP- 9A Pu-238 inventory had deposited on the earth's surface. Of this amount, approximately 23 percent had deposited in the Northern Hemisphere and 77 percent had deposited in the Southern Hemisphere.

The fallout of Sr-90 resulting from nuclear weapons testing in the upper atmosphere has been evaluated as a function of reentry latitude with the results shown previously in Figure 4-2 (References 4 and 5) The fallout patterns are controlled by worldwide atmospheric circulation patterns. A comparison of Figure 4-2 with the Pu-238 fallout patterns described in References 9 and 10, a reentry latitude of 25° S. is indicated for SNAP-9A. This means that although the actual injection latitude of SNAP-9A was 11° S. latitude, a latitude of 25 S., when used with the high altitude release model described in References 4 and 5, most nearly approximates measured Pu- 238 concentrations.

The time behavior of ground-level airborne concentrations as a function of time after release and release altitude was shown previously in Figure 4-1 based on the models presented in Reference 5. A comparison of Figures 4-1 with information in Reference 6 indicates a modeled release altitude of between 135,000 and 150,000 feet.

An analysis based in Reference 5 indicates that the high altitude vaporization of Pu-238 at 150,000 feet and 0° latitude would result in an estimated 1.82×10^{-3} excess cancer fatalities per Ci of vaporized Pu-238 released. (It should be noted that all subsequent use of Pu-238 in space nuclear systems involved Pu-238 dioxide, not subject to significant vaporization and far less hazardous due to its particle size distribution.) This includes consideration of all population exposure pathways resulting in inhalation, ingestion, and external radiation doses. The relative risk due to injection at latitudes other than 0° latitude, accounting for actual worldwide distributions of land and population was shown previously in Figure 4-3. For an injection latitude of 25° S. latitude, which best models the SNAP-9A fallout pattern, the relative risk index, r_i, is 0.32. Therefore, the consequences of the SNAP-9A reentry are estimated as follows:

$$H = (17{,}000\ Ci\,Pu-238)\left(\frac{1.18\ 10^{-3} excess\ cancer\ fatalities}{Ci\,Pu-238}\right)(0.32) \qquad (4)$$

$$= 6.4\ excess\ cancer\ fatalities$$

The predicted cancer fatalities are expected to occur over a period of 20 to 30 years following the incident.

5.2 COSMOS 954

COSMOS 954 disassembled due to reentry heating, resulting in a fallout footprint of approximately 50,000 km^2 centered at 62° N. latitude and 105° W. longitude in northern Canada (References 3, 6, and 7). An examination of the fallout footprint debris concluded that approximately 80 percent of the reactor fuel had vaporized on reentry with the remaining 20 percent depositing as non-inhalable particulates in the footprint area. The reactor was assumed to be operating just prior to breakup.

The radiological consequences of the COSMOS 954 reentry has been estimated base on Equation 3 of Section 4.1 with the following parameters:

r_i = 1.4

f_1 = 0.80

ρ = 1.44 *persons/km^2 (data for Cell 61, Reference 4, Volume 3, Table 3.3-8)*

F_1 = 1.00

f_2 = 0.20

F_2 = 0.00

Using these values, Equation 2 results in an estimated 7.89 x 10^{-2} excess cancer fatalities resulting from the COSMOS 954 incident.

5.3 COSMOS 1402

The radiological consequences of the COSMOS 1402 reentry has been estimated based on Equation 2, corresponding to Case 2 for COSMOS 1900. Since the reentry latitude for the COSMOS 1402 reactor core was 12 degrees S. latitude, the r_i = 0.55. The resulting health effects due to complete reentry burnup are estimated to be 2.62 x 10^{-2} excess cancer fatalities.

5.4 SYSTEM RISK COMPARISON RESULTS

The results above indicated that the estimated risk resulting from the reentry of SNAP-9A, COSMOS 954, COSMOS 1402 and COSMOS 1900 are 6.40, 7.89 x 10^{-2} 2.62 x 10^{-2} and 5.15 x 10^{-3} excess cancer fatalities, respectively.. The differences in risk are due in part to the assumptions identified above relating to injection latitudes and population densities. Although the total Curie inventory of SNAP-9A was much smaller than COSMOS 954, and COSMOS 1402, and COSMOS 1900, consideration must be given to the half-lives, inventory, and internal dose rate conversion factors of the radionuclides controlling the risk in each case. Pu-238 is an alpha emitter with a half-life of 86.4 years. The fission products associated with COSMOS 954 that contribute to the risk are predominately Sr-90, Cs-137, and Ce-144 with half-lives of 27.7, 30.0, and 0.78 years, respectively. The noble gases and iodines are released at high altitude and most of the very short lived radionuclides that account for most of the radioactive inventory will have decayed before reaching ground level or shortly thereafter. The fission products are beta/gamma emitters with a Quality Factor of 1, while Pu-238 is an alpha emitter with a Quality Factor of 20 (Reference 11). Only long-lived fission products and transuranics contribute to the COSMOS 1900 risks.

The above risk assessment for SNAP-9A, COSMOS 954, COSMOS 1402 and COSMOS 1900 should be viewed in light of natural background radiation levels and radionuclide inventories in the atmosphere resulting from nuclear weapons testing in the past.

The natural background radiation levels in the United States average approximately 125 mrem/yr to the whole body, including 45 mrem/yr due to cosmic radiation, 60 mrem/yr due to external exposure to natural terrestrial radiation, and 20 mrem/yr due to inhalation and ingestion of natural terrestrial radionuclides. Actual radiation at any location on earth will be a function of altitude, and local soil and rock composition. Assuming that the value of 125 mrem/yr is representative of the worldwide average, and assuming a world population of on the order of 4×10^9 persons, the resulting population dose due to natural background radiation is 5×10^8 person-rem/yr. The total risks of SNAP-9A, COSMOS 954, COSMOS 1402, and COSMOS 1900 is estimated to be 5.43×10^4 person-rem (6.52 excess cancer fatalities), or 0.011 percent of background radiation, assuming that the total population dose risk from these systems accumulated in a single year. In reality, the population dose risk would accumulate over a period of years, so the percentage of background is far less than reported.

Since the first nuclear weapons test at Alamogordo, New Mexico on July 16, 1945, approximately 3.6×10^5 Ci of Pu-239 and Pu-240 together have been injected into the atmosphere (Reference 8). SNAP-9A resulted in the addition of 17,000 Ci of Pu-238, representing almost all the Pu-238 in the atmosphere. Hence, SNAP-9A represents about 4.5 percent of all the plutonium initially injected into the atmosphere on a Curie basis as a result of man-related activities. It should also be noted the Pu-238 has a half-life of 86.4 years, while the half-lives of Pu-239 and Pu-240 are 2.44×10^4 and 6.58×10^3 years, respectively, so the Pu-238 will be removed faster from the global environment.

Prior nuclear weapons testing in the atmosphere also resulted in an initial inventory of 1.56×10^7 Ci of Sr-90 (Reference 11). This should be compared with an estimated Sr-90 for COSMOS 954, COSMOS 1402 and COSMOS 1900 (pre-boost) on the order of 50 ci each. Hence, the additional Sr-90 due to COSMOS 954, COSMOS 1402, and COSMOS 1900 represents about 0.00096 percent of that due to global fallout from nuclear weapon testing.

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Appendix A

Radionuclide Inventories

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233 DAYS OPERATION & 0 DAYS SHUTDOWN
POWER=   0.07MW, BURNUP=     22.MWD, FLUX= 1.60E+13N/CM**2-SEC

                                                  NUCLIDE RADIOACTIVITY, CURIES
                                               BASIS = 30.167KGOF FUEL 93%U-235 & 7%U-239
         CHARGE   DISCHARGE    1.SEC     10.SEC    100.SEC   1000.SEC  10000.SEC100000.SEC*******SEC*******SEC*******SEC*******SEC
HE  4   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
TL207   0.00E-01  9.66E-09  9.66E-09  9.66E-09  9.66E-09  9.67E-09  9.70E-09  9.75E-09  1.06E-08  2.05E-08  3.10E-07  1.57E-05
TL208   0.00E-01  2.43E-09  2.43E-09  2.43E-09  2.43E-09  2.43E-09  2.45E-09  2.48E-09  2.59E-09  5.11E-09  1.90E-08  2.05E-08
TL209   0.00E-01  2.45E-13  2.45E-13  2.45E-13  2.45E-13  2.45E-13  2.39E-13  2.47E-13  2.67E-13  5.22E-13  2.80E-12  2.51E-11
PB206   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PB207   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PB208   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PB209   0.00E-01  1.11E-11  1.11E-11  1.11E-11  1.11E-11  1.11E-11  1.12E-11  1.07E-11  1.21E-11  2.37E-11  1.27E-10  1.14E-09
PB210   0.00E-01  2.00E-16  2.00E-16  2.00E-16  2.00E-16  2.00E-16  2.01E-16  2.04E-16  2.34E-16  7.59E-15  7.20E-14  4.17E-11
PB211   0.00E-01  9.69E-09  9.69E-09  9.69E-09  9.69E-09  9.69E-09  9.69E-09  9.78E-09  1.06E-08  2.05E-08  3.11E-07  1.59E-05
PB212   0.00E-01  6.75E-09  6.75E-09  6.75E-09  6.75E-09  6.75E-09  6.75E-09  6.75E-09  7.20E-09  1.42E-08  5.28E-08  5.73E-09
PB214   0.00E-01  3.15E-14  3.15E-14  3.15E-14  3.15E-14  3.15E-14  3.10E-14  3.16E-14  3.38E-14  8.36E-14  1.88E-12  1.51E-10
BI209   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BI210   0.00E-01  2.00E-16  2.00E-16  2.00E-16  2.00E-16  2.00E-16  2.00E-16  2.00E-16  2.18E-16  7.59E-15  7.20E-14  4.17E-11
BI211   0.00E-01  9.69E-09  9.69E-09  9.69E-09  9.70E-09  9.69E-09  9.73E-09  9.78E-09  1.06E-08  2.05E-09  3.11E-07  1.53E-05
BI212   0.00E-01  6.75E-09  6.75E-09  6.75E-09  6.75E-09  6.75E-09  6.75E-09  6.89E-09  7.20E-09  1.42E-08  5.28E-08  5.73E-08
BI213   0.00E-01  1.11E-11  1.11E-11  1.11E-11  1.11E-11  1.11E-11  1.08E-11  1.12E-11  1.21E-11  2.37E-11  1.27E-10  1.14E-09
BI214   0.00E-01  3.15E-14  3.15E-14  3.15E-14  3.15E-14  3.15E-14  3.03E-14  3.16E-14  3.38E-14  8.33E-14  1.88E-12  1.51E-10
PO210   0.00E-01  4.53E-17  4.53E-17  4.53E-17  4.53E-17  4.53E-17  4.53E-17  4.61E-17  5.44E-17  2.24E-16  4.75E-14  4.17E-11
PO211   0.00E-01  2.91E-11  2.91E-11  2.92E-11  2.92E-11  2.91E-11  2.92E-11  2.93E-11  3.18E-11  6.15E-11  9.34E-10  4.73E-08
PO212   0.00E-01  4.32E-09  4.32E-09  4.32E-09  4.32E-09  4.32E-09  4.32E-09  4.41E-09  4.61E-09  9.09E-09  3.38E-08  3.67E-08
PO213   0.00E-01  1.09E-11  1.09E-11  1.09E-11  1.09E-11  1.09E-11  1.06E-11  1.10E-11  1.19E-11  2.32E-11  1.24E-10  1.12E-09
PO214   0.00E-01  3.15E-14  3.15E-14  3.15E-14  3.15E-14  3.15E-14  3.03E-14  3.15E-14  3.38E-14  8.35E-14  1.88E-12  1.51E-10
PO215   0.00E-01  9.69E-09  9.70E-09  9.69E-09  9.69E-09  9.69E-09  9.70E-09  9.78E-09  1.06E-08  2.65E-08  3.11E-07  1.53E-05
PO216   0.00E-01  6.75E-09  6.75E-09  6.77E-09  6.76E-09  6.75E-09  6.75E-09  6.76E-09  7.20E-09  1.42E-08  5.28E-08  5.73E-08
PO218   0.00E-01  3.15E-14  3.15E-14  3.15E-14  3.15E-14  3.15E-14  3.15E-14  3.16E-14  3.38E-14  8.35E-14  1.88E-12  1.51E-10
AT217   0.00E-01  1.11E-11  1.11E-11  1.11E-11  1.11E-11  1.11E-11  1.11E-11  1.12E-11  1.21E-11  2.37E-11  1.27E-10  1.14E-09
RN219   0.00E-01  9.69E-09  9.69E-09  9.69E-09  9.69E-09  9.69E-09  9.70E-09  9.79E-09  1.06E-08  2.05E-08  3.11E-07  1.53E-05
RN220   0.00E-01  6.75E-09  6.75E-09  6.75E-09  6.75E-09  6.75E-09  6.75E-09  6.76E-09  7.20E-09  1.42E-08  5.28E-08  5.73E-08
RN222   0.00E-01  3.15E-14  3.15E-14  3.15E-14  3.15E-14  3.15E-14  3.15E-14  3.15E-14  3.37E-14  8.35E-14  1.88E-12  1.51E-10
FR221   0.00E-01  1.11E-11  1.11E-11  1.11E-11  1.11E-11  1.11E-11  1.11E-11  1.12E-11  1.21E-11  2.37E-11  1.27E-10  1.14E-09
FR221   0.00E-01  1.83E-10  1.83E-10  1.83E-10  1.83E-10  1.83E-10  1.83E-10  1.84E-10  1.97E-10  3.55E-10  4.35E-09  2.21E-07
RA223   0.00E-01  9.69E-09  9.69E-09  9.69E-09  9.69E-09  9.69E-09  9.70E-09  9.73E-09  1.06E-08  2.05E-08  3.11E-07  1.53E-05
RA224   0.00E-01  6.75E-09  6.75E-09  6.75E-09  6.75E-09  6.75E-09  6.75E-09  6.75E-09  7.20E-09  1.42E-08  5.28E-08  5.73E-08
RA225   0.00E-01  1.24E-11  1.24E-11  1.24E-11  1.24E-11  1.24E-11  1.24E-11  1.25E-11  1.34E-11  2.35E-11  1.27E-10  1.14E-09
RA226   0.00E-01  3.15E-14  3.15E-14  3.15E-14  3.15E-14  3.15E-14  3.15E-14  3.19E-14  3.54E-14  8.36E-14  1.88E-12  1.51E-10
RA228   0.00E-01  2.19E-15  2.19E-16  2.19E-15  2.19E-16  2.19E-16  2.19E-16  2.21E-16  2.45E-16  5.73E-16  1.19E-14  4.53E-13
AC225   0.00E-01  1.11E-11  1.11E-11  1.11E-11  1.11E-11  1.11E-11  1.11E-11  1.12E-11  1.21E-11  2.37E-11  1.27E-10  1.14E-09
AC227   0.00E-01  1.30E-09  1.30E-08  1.30E-09  1.30E-08  1.30E-08  1.30E-08  1.31E-08  1.41E-09  2.54E-09  3.11E-07  1.53E-05
AC228   0.00E-01  2.19E-16  2.19E-16  2.19E-15  2.19E-16  2.19E-16  2.19E-16  2.19E-15  2.45E-16  5.73E-15  1.18E-14  4.53E-13
TH227   0.00E-01  1.08E-08  1.08E-08  1.08E-08  1.08E-08  1.08E-08  1.08E-08  1.09E-08  1.17E-08  2.20E-08  3.07E-07  1.56E-05
TH228   0.00E-01  6.74E-09  6.74E-09  6.74E-09  6.74E-09  6.74E-09  6.74E-09  6.81E-09  7.52E-09  1.42E-08  5.28E-08  5.73E-09
TH229   0.00E-01  1.43E-11  1.43E-11  1.43E-11  1.43E-11  1.43E-11  1.43E-11  1.44E-11  1.54E-11  2.55E-11  1.27E-10  1.14E-09
TH230   0.00E-01  2.72E-10  2.72E-10  2.72E-10  2.72E-10  2.72E-10  2.72E-10  2.74E-10  2.94E-10  4.87E-10  2.42E-09  2.18E-08
TH231   0.00E-01  6.01E-02  6.01E-02  6.01E-02  6.01E-02  6.01E-02  6.01E-02  6.01E-02  6.01E-02  6.01E-02  6.01E-02  6.01E-02
TH232   0.00E-01  8.07E-15  8.07E-15  8.07E-15  8.07E-15  8.07E-15  8.07E-15  8.13E-15  8.70E-15  1.44E-14  7.18E-14  6.45E-13
TH233   0.00E-01  3.68E-08  3.68E-08  3.66E-08  3.49E-08  2.18E-08  1.98E-10  7.33E-31  0.00E-01  0.00E-01  0.00E-01  0.00E-01
TH234   0.00E-01  7.03E-04  7.03E-04  7.03E-04  7.03E-04  7.03E-04  7.03E-04  7.03E-04  7.04E-04  7.04E-04  7.04E-04  7.04E-04
PA231   0.00E-01  1.02E-05  1.02E-06  1.02E-05  1.02E-06  1.02E-06  1.02E-06  1.03E-06  1.06E-06  1.43E-05  5.09E-05  4.15E-05
PA232   0.00E-01  1.94E-05  1.94E-05  1.94E-05  1.94E-05  1.93E-05  1.82E-05  1.06E-05  4.44E-08  0.00E-01  0.00E-01  0.00E-01
PA233   0.00E-01  1.27E-06  1.27E-06  1.27E-06  1.27E-06  1.27E-06  1.27E-06  1.27E-06  1.33E-06  1.54E-06  1.55E-06  1.55E-06
PA234M  0.00E-01  7.03E-04  7.03E-04  7.03E-04  7.03E-04  7.04E-04  7.04E-04  7.04E-04  7.04E-04  7.04E-04  7.04E-04  7.04E-04
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   233 DAYS OPERATION & 0 DAYS SHUTDOWN
   POWER=   0.07MW, BURNUP=     22.MWD, FLUX= 1.60E+13N/CM**2-SEC

                                                         NUCLIDE RADIOACTIVITY, CURIES
                                                     BASIS = 30.167KGOF FUEL 93%U-235 & 7%U-238
          CHARGE   DISCHARGE     1.SEC     10.SEC    100.SEC   1000.SEC  10000.SEC100000.SEC•••••••SEC•••••••SEC•••••••SEC•••••••SEC
PA234    0.00E-01  7.04E-07  7.04E-07  7.04E-07  7.04E-07  7.04E-07  7.03E-07  7.03E-07  7.04E-07  7.04E-07  7.04E-07  7.04E-07
 U232    0.00E-01  7.43E-08  7.43E-08  7.43E-08  7.43E-08  7.43E-08  7.44E-08  7.48E-08  7.53E-08  7.51E-08  7.32E-08  5.59E-08
 U233    0.00E-01  3.75E-07  3.75E-07  3.75E-07  3.75E-07  3.75E-07  3.75E-07  3.75E-07  3.75E-07  3.75E-07  3.75E-07  3.75E-07
 U234    0.00E-01  7.84E-05  7.84E-05  7.84E-05  7.84E-05  7.84E-05  7.84E-05  7.84E-05  7.84E-05  7.84E-05  7.84E-05  7.84E-05
 U235    6.01E-02  6.01E-02  6.01E-02  6.01E-02  5.01E-02  6.01E-02  6.01E-02  6.01E-02  6.01E-02  6.01E-02  6.01E-02  6.01E-02
 U236    0.00E-01  4.09E-04  4.09E-04  4.09E-04  4.09E-04  4.09E-04  4.09E-04  4.09E-04  4.09E-04  4.09E-04  4.09E-04  4.09E-04
 U237    0.00E-01  8.27E+00  8.27E+00  8.27E+00  8.27E+00  8.26E+00  8.17E+00  7.34E+00  2.52E+00  5.73E-05  3.17E-12  8.17E-13
 U238    7.04E-04  7.04E-04  7.04E-04  7.04E-04  7.04E-04  7.04E-04  7.04E-04  7.04E-04  7.04E-04  7.04E-04  7.04E-04  7.04E-04
 U239    0.00E-01  6.85E+02  6.84E+02  6.81E+02  6.52E+02  4.19E+02  5.02E+00  3.07E-19  0.00E-01  0.00E-01  0.00E-01  0.00E-01
 U240    0.00E-01  5.80E-06  5.80E-06  5.80E-06  5.79E-06  5.72E-06  5.06E-06  1.49E-06  6.81E-12  1.59E-32  1.58E-32  1.59E-32
NP236    0.00E-01  2.25E-07  2.25E-07  2.25E-07  2.25E-07  2.23E-07  2.06E-07  9.39E-08  3.56E-11  0.00E-01  0.00E-01  0.00E-01
NP237    0.00E-01  1.48E-06  1.48E-06  1.48E-06  1.48E-06  1.48E-06  1.48E-06  1.49E-06  1.53E-06  1.55E-06  1.55E-06  1.55E-06
NP238    0.00E-01  1.77E-03  1.77E-03  1.77E-03  1.77E-03  1.76E-03  1.70E-03  1.21E-03  3.88E-05  4.53E-20  0.00E-01  0.00E-01
NP239    0.00E-01  6.85E+02  6.85E+02  6.85E+02  6.85E+02  6.84E+02  6.66E+02  4.90E+02  2.27E+01  1.03E-12  3.69E-19  3.67E-19
NP240M   0.00E-01  5.80E-06  5.80E-06  5.80E-06  5.80E-06  5.76E-06  5.10E-06  1.49E-05  6.87E-12  1.53E-32  1.58E-32  1.53E-32
NP240    0.00E-01  2.66E-03  2.66E-03  2.65E-03  2.61E-03  2.21E-03  4.25E-04  2.89E-11  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PU236    0.00E-01  1.03E-08  1.03E-08  1.03E-08  1.03E-08  1.03E-08  1.03E-08  1.03E-08  1.03E-08  9.60E-09  4.80E-09  4.65E-12
PU238    0.00E-01  4.92E-06  4.92E-06  4.92E-06  4.92E-06  4.92E-06  4.92E-06  4.96E-06  5.03E-06  5.02E-06  4.91E-06  3.93E-06
PU239    0.00E-01  1.54E-02  1.54E-02  1.54E-02  1.54E-02  1.54E-02  1.54E-02  1.55E-02  1.56E-02  1.56E-02  1.56E-02  1.55E-02
PU240    0.00E-01  5.88E-06  5.88E-06  5.88E-06  5.88E-06  5.88E-06  5.88E-06  5.88E-06  5.88E-06  5.89E-06  5.89E-06  5.95E-06
PU241    0.00E-01  1.53E-07  1.53E-07  1.53E-07  1.53E-07  1.53E-07  1.53E-07  1.53E-07  1.53E-07  1.51E-07  1.32E-07  3.40E-08
PU242    0.00E-01  2.63E-16  2.63E-16  2.63E-16  2.63E-16  2.63E-16  2.63E-16  2.63E-16  2.63E-16  2.63E-16  2.63E-16  2.63E-16
PU243    0.00E-01  2.48E-14  2.48E-14  2.48E-14  2.47E-14  2.39E-14  1.69E-14  5.43E-16  4.20E-31  0.00E-01  0.00E-01  0.00E-01
PU244    0.00E-01  1.59E-32  1.59E-32  1.59E-32  1.59E-32  1.59E-32  1.59E-32  1.59E-32  1.59E-32  1.59E-32  1.59E-32  1.59E-32
PU245    0.00E-01  3.25E-28  3.25E-28  3.25E-28  3.25E-28  3.25E-28  3.25E-28  3.25E-28  2.59E-35  0.00E-01  0.00E-01  0.00E-01
AM241    0.00E-01  4.99E-11  4.99E-11  4.99E-11  4.99E-11  4.99E-11  4.99E-11  5.06E-11  5.76E-11  1.27E-10  7.69E-10  3.94E-09
AM242M   0.00E-01  1.87E-15  1.87E-15  1.87E-15  1.87E-15  1.87E-15  1.87E-15  1.87E-15  1.87E-15  1.87E-15  1.85E-15  1.62E-15
AM242    0.00E-01  1.31E-11  1.31E-11  1.31E-11  1.30E-11  1.29E-11  1.16E-11  3.92E-12  1.95E-15  1.87E-15  1.85E-15  1.62E-15
AM243    0.00E-01  3.66E-19  3.66E-19  3.66E-19  3.66E-19  3.66E-19  3.67E-19  3.69E-19  3.69E-19  3.63E-19  3.69E-19  3.67E-19
AM244    0.00E-01  1.13E-18  1.13E-18  1.13E-18  1.13E-18  1.13E-18  1.13E-18  2.55E-35  2.06E-35  2.06E-35  2.06E-35  2.05E-35
AM245    0.00E-01  1.67E-26  1.67E-26  1.67E-26  1.67E-26  1.67E-26  1.67E-26  3.45E-28  3.21E-35  0.00E-01  0.00E-01  0.00E-01
CM242    0.00E-01  2.21E-12  2.21E-12  2.21E-12  2.21E-12  2.21E-12  2.21E-12  2.23E-12  2.14E-12  1.38E-12  1.79E-14  1.33E-15
CM243    0.00E-01  9.25E-19  8.25E-19  8.25E-19  8.25E-19  8.25E-19  8.25E-19  8.25E-19  8.25E-19  8.20E-19  7.71E-19  4.15E-19
CM244    0.00E-01  2.14E-21  2.14E-21  2.14E-21  2.14E-21  2.14E-21  2.14E-21  2.14E-21  2.14E-21  2.14E-21  2.14E-21 -1.93E-22
CM245    0.00E-01  1.41E-34  1.41E-34  1.41E-34  1.41E-34  1.41E-34  1.41E-34  6.17E-34  6.75E-34  6.75E-34  6.75E-34  6.75E-34
CM246    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CM247    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CM248    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CM249    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CM250    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BK249    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BK250    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CF249    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CF250    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CF251    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CF252    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CF253    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CF254    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
ES253    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
 TOTAL   6.08E-02  1.38E+03  1.38E+03  1.37E+03  1.35E+03  1.11E+03  6.80E+02  4.98E+02  2.54E+01  1.39E-01  1.38E-01  1.39E-01
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235 DAYS OPERATION & 0 DAYS SHUTDOWN
POWER=   0.07MW, BURNUP=     22.MWD, FLUX= 1.60E+13N/CM**2-SEC

                                                       NUCLIDE RADIOACTIVITY, CURIES
                                                    BASIS = 30.167KGOF FUEL 93%U-235 & 7%U-238
          CHARGE   DISCHARGE     1.SEC    10.SEC    100.SEC  1000.SEC  10000.SEC100000.SEC*******SEC*******SEC*******SEC*******SEC
 H  3    0.00E-01  3.36E-01  3.36E-01  3.36E-01  3.36E-01  3.36E-01  3.36E-01  3.35E-01  3.35E-01  3.30E-01  2.81E-01  5.63E-02
ZN 72    0.00E-01  1.00E-05  1.00E-05  1.00E-05  1.00E-05  9.96E-06  9.60E-06  6.61E-06  1.59E-07  1.04E-23  0.00E-01  0.00E-01
GA 72    0.00E-01  1.00E-05  1.00E-05  1.00E-05  1.00E-05  1.00E-05  9.97E-06  8.38E-06  2.28E-07  1.49E-23  0.00E-01  0.00E-01
GE 72    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
GA 73    0.00E-01  5.00E-05  5.00E-05  5.00E-05  4.98E-05  4.81E-05  3.38E-05  9.83E-07  4.30E-22  0.00E-01  0.00E-01  0.00E-01
GE 73    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
GA 74    0.00E-01  9.03E-01  9.01E-01  8.90E-01  7.80E-01  2.09E-01  4.03E-07  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
GE 74    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
GA 75    0.00E-01  1.10E+01  1.10E+01  1.04E+01  6.20E+00  3.43E-02  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
GE 75M   0.00E-01  1.06E+01  1.06E+01  1.06E+01  8.25E+00  5.48E-02  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
GE 75    0.00E-01  1.10E+01  1.10E+01  1.10E+01  1.10E+01  9.93E+00  2.79E+00  8.70E-06  0.00E-01  0.00E-01  0.00E-01  0.00E-01
AS 75    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
GA 76    0.00E-01  1.72E+01  1.68E+01  1.30E+01  1.97E+00  6.72E-09  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
GE 76    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
AS 76    0.00E-01  8.86E-04  8.86E-04  8.86E-04  9.85E-04  8.90E-04  8.24E-04  4.29E-04  6.19E-07  0.00E-01  0.00E-01  0.00E-01
SE 76    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
GE 77M   0.00E-01  2.58E+01  2.55E+01  2.27E+01  7.15E+00  6.89E-05  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
GE 77    0.00E-01  9.88E+00  9.88E+00  9.88E+00  9.87E+00  9.73E+00  8.34E+00  1.80E+00  3.94E-07  0.00E-01  0.00E-01  0.00E-01
AS 77    0.00E-01  2.95E+01  2.95E+01  2.95E+01  2.95E+01  2.94E+01  2.85E+01  1.97E+01  2.32E-01  8.30E-21  0.00E-01  0.00E-01
SE 77M   0.00E-01  8.85E-02  8.85E-02  8.85E-02  9.93E-02  8.93E-02  8.56E-02  5.91E-02  6.96E-04  2.43E-23  0.00E-01  0.00E-01
SE 77    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
GE 78    0.00E-01  4.55E+01  4.55E+01  4.54E+01  4.49E+01  3.99E+01  1.25E+01  9.32E-05  0.00E-01  0.00E-01  0.00E-01  0.00E-01
AS 78M   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
AS 78    0.00E-01  4.67E+01  4.67E+01  4.67E+01  4.67E+01  4.62E+01  2.90E+01  1.60E-05  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SE 78    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
AS 79    0.00E-01  7.39E+01  7.38E+01  7.30E+01  6.50E+01  2.05E+01  1.97E-04  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SE 79M   0.00E-01  7.39E+01  7.39E+01  7.39E+01  7.27E+01  3.32E+01  3.47E-04  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SE 79    0.00E-01  6.32E-04  6.32E-04  6.32E-04  6.32E-04  6.32E-04  6.32E-04  6.32E-04  6.32E-04  6.32E-04  6.32E-04  6.32E-04
BR 79    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
AS 80    0.00E-01  1.17E+02  1.12E+02  7.42E+01  1.26E+00  2.47E-18  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SE 80    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BR 80M   0.00E-01  1.80E-08  1.80E-08  1.80E-08  1.79E-08  1.72E-08  1.16E-08  2.22E-10  1.46E-27  0.00E-01  0.00E-01  0.00E-01
BR 80    0.00E-01  8.70E-02  8.70E-02  8.65E-02  8.15E-02  4.52E-02  1.23E-04  2.38E-10  1.56E-27  0.00E-01  0.00E-01  0.00E-01
KR 80    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
AS 81    0.00E-01  1.84E+02  1.81E+02  1.50E+02  2.26E+01  1.39E-07  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SE 81M   0.00E-01  1.84E+02  1.84E+02  1.84E+02  1.82E+02  1.52E+02  2.45E+01  2.94E-07  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SE 81    0.00E-01  1.91E+02  1.91E+02  1.91E+02  1.90E+02  1.80E+02  3.63E+01  4.37E-07  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BR 81    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
KR 81M   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
KR 81    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SE 82    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BR 82M   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BR 82    0.00E-01  1.28E-02  1.28E-02  1.28E-02  1.28E-02  1.28E-02  1.21E-02  7.45E-03  5.49E-05  2.65E-26  0.00E-01  0.00E-01
KR 82    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SE 83M   0.00E-01  1.17E-03  1.16E-03  1.06E-03  4.35E-04  5.07E-06  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SE 83    0.00E-01  3.56E+02  3.56E+02  3.55E+02  3.40E+02  2.25E+02  3.51E+00  3.05E-18  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BR 83    0.00E-01  3.78E+02  3.78E+02  3.78E+02  3.78E+02  3.71E+02  2.03E+02  1.55E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
KR 83M   0.00E-01  3.78E+02  3.78E+02  3.79E+02  3.78E+02  3.78E+02  3.14E+02  6.20E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
KR 83    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SE 84    0.00E-01  6.38E+02  6.36E+02  6.16E+02  4.50E+02  1.93E+01  4.00E-13  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BR 84M   0.00E-01  1.84E+01  1.84E+01  1.81E+01  1.52E+01  2.69E+00  8.02E-08  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BR 84    0.00E-01  6.38E+02  6.38E+02  6.38E+02  6.35E+02  4.93E+02  1.88E+01  1.19E-13  0.00E-01  0.00E-01  0.00E-01  0.00E-01
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233 DAYS OPERATION & 0 DAYS SHUTDOWN
POWER=   0.09MW, BURNUP=     22.MWD, FLUX= 1.50E+13N/CM**2-SEC

                                                    NUCLIDE RADIOACTIVITY, CURIES
                                                BASIS = 30.167KGOF FUEL 93%U-235 & 7%U-238
           CHARGE  DISCHARGE      1.SEC    10.SEC   100.SEC  1000.SEC 10000.SEC100000.SEC*******SEC*******SEC*******SEC*******SEC
KR 84    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SE 85    0.00E-01  7.33E+02  7.20E+02  6.14E+02  1.24E+02  1.40E-05  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BR 85    0.00E-01  9.11E+02  9.10E+02  9.02E+02  7.24E+02  2.37E+01  2.11E-14  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
KR 85M   0.00E-01  9.11E+02  9.11E+02  9.11E+02  9.11E+02  8.84E+02  5.96E+02  1.16E+01  9.14E-17  0.00E-01  0.00E-01  0.00E-01
KR 85    0.00E-01  1.08E+01  1.08E+01  1.08E+01  1.08E+01  1.08E+01  1.06E+01  1.08E+01  1.09E+01  1.05E+01  8.83E+00  1.42E+00
RB 85    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BR 86    0.00E-01  1.77E-07  1.75E-07  1.56E-07  4.90E-08  4.71E-13  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
KR 86    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
RB 86M   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
RB 86    0.00E-01  2.05E-02  2.05E-02  2.05E-02  2.05E-02  2.05E-02  2.04E-02  1.96E-02  1.33E-02  2.91E-04  4.78E-21  0.00E-01
SR 86    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BR 87    0.00E-01  3.31E-17  3.31E-17  3.31E-17  3.31E-17  3.93E-22  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
KR 87    0.00E-01  1.64E+03  1.64E+03  1.63E+03  1.61E+03  1.41E+03  3.58E+02  4.19E-04  0.00E-01  0.00E-01  0.00E-01  0.00E-01
RB 87    0.00E-01  1.82E-08  1.82E-08  1.82E-08  1.82E-08  1.82E-08  1.82E-08  1.82E-08  1.82E-08  1.82E-08  1.82E-08  1.82E-08
SR 87M   0.00E-01  1.14E-07  1.14E-07  1.14E-07  1.13E-07  1.06E-07  5.77E-08  1.26E-10  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SR 87    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BR 88    0.00E-01  1.66E-27  1.66E-27  1.66E-27  1.66E-27  1.94E-44  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
KR 88    0.00E-01  2.15E+03  2.15E+03  2.15E+03  2.14E+03  2.01E+03  1.04E+03  2.22E+00  0.00E-01  0.00E-01  0.00E-01  0.00E-01
RB 88    0.00E-01  2.23E+03  2.23E+03  2.23E+03  2.23E+03  2.16E+03  1.21E+03  2.49E+00  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SR 88    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BR 89    0.00E-01  7.80E-38  7.80E-38  7.80E-38  7.44E-44  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
KR 89    0.00E-01  2.83E+03  2.82E+03  2.73E+03  1.97E+03  7.66E+01  5.94E-13  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
RB 89    0.00E-01  3.08E+03  3.08E+03  3.07E+03  3.03E+03  1.78E+03  2.11E+00  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SR 89    0.00E-01  3.01E+03  3.01E+03  3.01E+03  3.01E+03  3.01E+03  3.01E+03  2.97E+03  2.59E+03  6.43E+02  6.01E-04  0.00E-01
 Y 89    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
KR 90    0.00E-01  2.64E+03  2.59E+03  2.14E+03  3.23E+02  1.93E-06  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
RB 90    0.00E-01  3.19E+03  3.19E+03  3.15E+03  2.48E+03  7.10E+01  1.91E-14  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SR 90    0.00E-01  6.31E+01  6.31E+01  6.31E+01  6.31E+01  6.31E+01  6.31E+01  6.31E+01  6.30E+01  6.25E+01  5.83E+01  2.83E+01
 Y 90M   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
 Y 90    0.00E-01  6.31E+01  6.31E+01  6.31E+01  6.31E+01  6.31E+01  6.31E+01  6.31E+01  6.30E+01  6.25E+01  5.93E+01  2.93E+01
ZR 90    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
KR 91    0.00E-01  2.21E+03  2.07E+03  1.11E+03  2.16E+00  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
RB 91    0.00E-01  3.26E+03  3.24E+03  3.10E+03  1.38E+03  2.38E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SR 91    0.00E-01  3.38E+03  3.38E+03  3.38E+03  3.38E+03  3.32E+03  2.77E+03  4.62E+02  7.63E-06  0.00E-01  0.00E-01  0.00E-01
 Y 91M   0.00E-01  1.99E+03  1.99E+03  1.93E+03  1.93E+03  1.93E+03  1.77E+03  2.93E+02  4.93E-06  0.00E-01  0.00E-01  0.00E-01
 Y 91    0.00E-01  3.26E+03  3.26E+03  3.26E+03  3.26E+03  3.26E+03  3.26E+03  3.24E+03  2.87E+03  8.40E+02  3.90E-03  0.00E-01
ZR 91    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
KR 92    0.00E-01  1.72E+03  1.37E+03  1.71E+02  1.59E-07  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
RB 92    0.00E-01  3.20E+03  2.93E+03  1.25E+03  1.14E-02  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SR 92    0.00E-01  3.57E+03  3.57E+03  3.57E+03  3.54E+03  3.32E+03  1.75E+03  2.33E+00  0.00E-01  0.00E-01  0.00E-01  0.00E-01
 Y 92    0.00E-01  3.57E+03  3.57E+03  3.57E+03  3.57E+03  3.56E+03  3.11E+03  5.60E+01  3.15E-20  0.00E-01  0.00E-01  0.00E-01
ZR 92    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
KR 93    0.00E-01  1.11E+03  7.83E+02  3.46E+01  9.83E-13  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
RB 93    0.00E-01  2.99E+03  2.65E+03  9.37E+02  1.48E-02  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SR 93    0.00E-01  3.69E+03  3.68E+03  3.66E+03  3.22E+03  8.79E+02  1.99E-03  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
 Y 93    0.00E-01  3.75E+03  3.75E+03  3.75E+03  3.75E+03  3.71E+03  3.14E+03  5.75E+02  2.41E-05  0.00E-01  0.00E-01  0.00E-01
ZR 93    0.00E-01  1.39E-03  1.39E-03  1.39E-03  1.39E-03  1.39E-03  1.39E-03  1.39E-03  1.39E-03  1.39E-03  1.39E-03  1.39E-03
NB 93M   0.00E-01  2.79E-05  2.79E-05  2.79E-05  2.79E-05  2.79E-05  2.79E-05  2.81E-05  3.01E-05  4.47E-05  2.31E-04  1.12E-03
NB 93    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
KR 94    0.00E-01  5.37E+02  3.27E+02  3.86E+00  1.69E-19  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
RB 94    0.00E-01  2.22E+03  1.84E+03  2.46E+02  1.13E-07  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SR 94    0.00E-01  3.57E+03  3.56E+03  3.34E+03  1.51E+03  5.07E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
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233 DAYS OPERATION & 0 DAYS SHUTDOWN
POWER=   0.07MW, BURNUP=     22.MWD, FLUX= 1.60E+13N/CM**2-SEC

                                                      NUCLIDE RADIOACTIVITY, CURIES
                                                  BASIS = 30.167KGOF FUEL 93%U-235 & 7%U-238
            CHARGE  DISCHARGE      1.SEC     10.SEC    100.SEC   1000.SEC 10000.SEC100000.SEC*******SEC*******SEC*******SEC*******SEC
 Y 94     0.00E-01   3.82E+03   3.82E+03   3.81E+03   3.74E+03   2.30E+03   1.37E+01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
ZR 94     0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
RB 95     0.00E-01   1.66E+03   1.26E+03   1.04E+02   1.51E-09   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
SR 95     0.00E-01   3.45E+03   3.42E+03   3.05E+03   9.35E+02   1.89E-03   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
 Y 95     0.00E-01   4.12E+03   4.12E+03   4.11E+03   3.89E+03   1.53E+03   1.10E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
ZR 95     0.00E-01   3.94E+03   3.94E+03   3.94E+03   3.94E+03   3.94E+03   3.94E+03   3.89E+03   3.48E+03   1.15E+03   1.72E-02   0.00E-01
NB 95M    0.00E-01   8.09E+01   8.09E+01   8.09E+01   8.09E+01   8.09E+01   8.09E+01   8.04E+01   7.36E+01   2.43E+01   3.65E-04   0.00E-01
NB 95     0.00E-01   3.74E+03   3.74E+03   3.74E+03   3.74E+03   3.74E+03   3.74E+03   3.75E+03   3.73E+03   2.00E+03   3.73E-02   0.00E-01
MO 95     0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
 Y 96     0.00E-01   3.76E+03   3.74E+03   3.57E+03   2.27E+03   2.47E+01   5.78E-19   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
ZR 96     0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
NB 96     0.00E-01   1.04E-01   1.04E-01   1.04E-01   1.04E-01   1.03E-01   9.53E-02   4.49E-02   2.49E-05   0.00E-01   0.00E-01   0.00E-01
MO 96     0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
 Y 97     0.00E-01   3.75E+03   3.34E+03   1.18E+03   3.61E-02   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
ZR 97     0.00E-01   4.17E+03   4.17E+03   4.17E+03   4.16E+03   4.12E+03   3.72E+03   1.34E+03   5.02E-02   0.00E-01   0.00E-01   0.00E-01
NB 97M    0.00E-01   4.00E+03   4.00E+03   4.00E+03   4.00E+03   3.96E+03   3.58E+03   1.29E+03   4.83E-02   0.00E-01   0.00E-01   0.00E-01
NB 97     0.00E-01   4.17E+03   4.17E+03   4.17E+03   4.17E+03   4.15E+03   3.93E+03   1.35E+03   5.41E-02   0.00E-01   0.00E-01   0.00E-01
MO 97     0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
ZR 98     0.00E-01   3.51E+03   3.47E+03   3.13E+03   1.11E+03   3.33E-02   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
NB 98M    0.00E-01   3.51E+03   3.51E+03   3.50E+03   2.83E+03   2.17E+01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
NB 98     0.00E-01   2.46E+02   2.46E+02   2.45E+02   2.40E+02   1.96E+02   2.55E+01   3.57E-08   0.00E-01   0.00E-01   0.00E-01   0.00E-01
MO 98     0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
NB 99     0.00E-01   3.63E+03   3.61E+03   3.45E+03   2.24E+03   2.95E+01   4.53E-18   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
MO 99     0.00E-01   3.63E+03   3.63E+03   3.63E+03   3.63E+03   3.62E+03   3.53E+03   2.73E+03   2.05E+02   1.21E-09   0.00E-01   0.00E-01
TC 99M    1.00E-01   3.16E+03   3.16E+03   3.15E+03   3.16E+03   3.16E+03   3.15E+03   2.59E+03   1.96E+02   1.15E-09   0.00E-01   0.00E-01
TC 99     0.00E-01   9.38E-03   9.38E-03   9.38E-03   9.38E-03   9.38E-03   9.38E-03   9.41E-03   9.51E-03   9.52E-03   9.52E-03   9.52E-03
RU 99     0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
NB100     0.00E-01   3.38E+03   3.37E+03   3.26E+03   2.30E+03   7.20E+01   6.49E-14   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
MO100     0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
TC100     0.00E-01   2.96E-01   2.84E-01   1.97E-01   5.02E-03   5.89E-19   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
RU100     0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
NB101     0.00E-01   2.83E+03   2.80E+03   2.52E+03   8.93E+02   2.73E-02   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
MO101     0.00E-01   3.33E+03   3.33E+03   3.32E+03   3.20E+03   1.69E+03   1.29E+00   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
TC101     0.00E-01   3.36E+03   3.36E+03   3.36E+03   3.36E+03   2.77E+03   9.93E+00   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
RU101     0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
MO102     0.00E-01   2.77E+03   2.77E+03   2.74E+03   2.50E+03   9.70E+02   7.62E-02   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
TC102M    0.00E-01   1.39E+03   1.39E+03   1.39E+03   1.37E+03   7.47E+02   6.45E-02   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
TC102     0.00E-01   1.48E+03   1.47E+03   1.40E+03   1.25E+03   4.89E+02   3.84E-02   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
RU102     0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
MO103     0.00E-01   1.97E+03   1.95E+03   1.76E+03   6.44E+02   2.75E-02   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
TC103     0.00E-01   2.15E+03   2.15E+03   2.12E+03   1.32E+03   1.34E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
RU103     0.00E-01   2.14E+03   2.14E+03   2.14E+03   2.14E+03   2.14E+03   2.14E+03   2.10E+03   1.75E+03   2.82E+02   3.41E-06   0.00E-01
RH103M    0.00E-01   2.14E+03   2.14E+03   2.14E+03   2.14E+03   2.14E+03   2.14E+03   2.10E+03   1.75E+03   2.83E+02   3.41E-05   0.00E-01
RH103     0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
MO104     0.00E-01   1.17E+03   1.16E+03   1.07E+03   4.80E+02   1.61E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
TC104     0.00E-01   1.44E+03   1.44E+03   1.44E+03   1.40E+03   8.05E+02   2.49E+00   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
RU104     0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
RH104M    0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
RH104     0.00E-01   6.31E-05   6.21E-05   5.37E-05   1.26E-05   6.30E-12   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
PD104     0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
MO105     0.00E-01   7.98E+02   7.85E+02   6.71E+02   1.41E+02   2.38E-05   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
TC105     0.00E-01   9.22E+02   9.11E+02   8.07E+02   1.77E+02   2.97E-05   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
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295 DAYS OPERATION & 0 DAYS SHUTDOWN
POWER=   9.07MW, BURNUP=     22.MWD, FLUX= 1.60E+13N/CM**2-SEC

                                                       NUCLIDE RADIOACTIVITY, CURIES
                                                    BASIS = 30.167KGDF FUEL 93%U-235 & 7%U-239
          CHARGE  DISCHARGE     1.SEC    10.SEC   100.SEC  1000.SEC 10000.SEC100000.SEC*******SEC*******SEC*******SEC*******SEC
RU105   0.00E-01  9.22E+02  9.22E+02  9.22E+02  9.20E+02  8.85E+02  5.99E+02  1.21E+01  1.36E-16  0.00E-01  0.00E-01  0.00E-01
RH105M  0.00E-01  9.22E+02  9.22E+02  9.22E+02  9.21E+02  8.88E+02  6.01E+02  1.21E+01  1.36E-16  0.00E-01  0.00E-01  0.00E-01
RH105   0.00E-01  9.22E+02  9.22E+02  9.22E+02  9.22E+02  9.22E+02  9.13E+02  6.14E+02  4.93E+00  5.37E-21  0.00E-01  0.00E-01
PD105   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
TC106   0.00E-01  5.68E+02  5.57E+02  4.71E+02  8.72E+01  4.15E-06  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
RU106   0.00E-01  2.54E+02  2.54E+02  2.54E+02  2.54E+02  2.54E+02  2.54E+02  2.54E+02  2.49E+02  2.04E+02  2.86E+01  8.15E-08
RH106M  0.00E-01  6.79E-04  6.79E-04  6.78E-04  6.73E-04  6.21E-04  2.79E-04  9.39E-08  0.00E-01  0.00E-01  0.00E-01  0.00E-01
RH106   0.00E-01  2.54E+02  2.54E+02  2.54E+02  2.54E+02  2.54E+02  2.54E+02  2.54E+02  2.49E+02  2.04E+02  2.85E+01  8.15E-08
PD106   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
RU107   0.00E-01  2.22E+02  2.22E+02  2.16E+02  1.69E+02  1.42E+01  2.52E-10  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
RH107   0.00E-01  2.22E+02  2.22E+02  2.22E+02  2.21E+02  1.59E+02  1.44E+00  4.31E-21  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PD107M  0.00E-01  4.45E+01  4.45E+01  4.45E+01  4.43E+01  3.23E+01  2.93E-01  8.77E-22  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PD107   0.00E-01  1.76E-05  1.76E-05  1.76E-05  1.76E-05  1.76E-05  1.76E-05  1.76E-05  1.76E-05  1.76E-05  1.76E-05  1.76E-05
AG107   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
RU108   0.00E-01  1.48E+02  1.48E+02  1.45E+02  1.15E+02  1.14E+01  1.05E-09  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
RH108   0.00E-01  1.48E+02  1.48E+02  1.48E+02  1.22E+02  1.22E+01  1.12E-09  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PD108   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
AG108   0.00E-01  1.16E-09  1.16E-09  1.11E-09  7.20E-10  9.91E-12  2.16E-30  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CD108   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
RH109   0.00E-01  8.99E+01  8.79E+01  7.14E+01  8.92E+00  8.31E-09  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PD109M  0.00E-01  1.02E-04  1.02E-04  9.95E-05  7.97E-05  8.73E-06  2.16E-15  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PD109   0.00E-01  8.99E+01  8.99E+01  8.99E+01  9.98E+01  8.87E+01  7.89E+01  2.16E+01  5.76E-05  0.00E-01  0.00E-01  0.00E-01
AG109M  0.00E-01  8.99E+01  8.99E+01  8.99E+01  8.99E+01  8.89E+01  7.81E+01  2.15E+01  5.76E-05  1.65E-15  3.35E-16  4.02E-23
AG109   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CD109   0.00E-01  1.98E-15  1.98E-15  1.98E-15  1.98E-15  1.98E-15  1.98E-15  1.97E-15  1.94E-15  1.65E-15  3.36E-16  4.02E-23
RH110   0.00E-01  6.77E+01  5.89E+01  1.69E+01  6.45E-05  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PD110   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
AG110M  0.00E-01  1.62E-04  1.62E-04  1.62E-04  1.62E-04  1.62E-04  1.62E-04  1.61E-04  1.57E-04  1.13E-04  6.79E-05  2.74E-16
AG110   0.00E-01  1.52E-02  1.48E-02  1.14E-02  9.07E-04  2.10E-05  2.10E-05  2.10E-05  2.04E-05  1.53E-05  8.82E-07  3.55E-19
CD110   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PD111M  0.00E-01  2.84E+01  2.84E+01  2.84E+01  2.83E+01  2.74E+01  2.09E+01  8.55E-01  1.78E-14  0.00E-01  0.00E-01  0.00E-01
PD111   0.00E-01  2.13E+01  2.13E+01  2.13E+01  2.13E+01  2.11E+01  1.61E+01  6.93E-01  1.43E-14  0.00E-01  0.00E-01  0.00E-01
AG111M  0.00E-01  2.84E+01  2.84E+01  2.84E+01  2.84E+01  2.88E+01  2.11E+01  9.03E-01  1.88E-14  0.00E-01  0.00E-01  0.00E-01
AG111   0.00E-01  2.82E+01  2.82E+01  2.82E+01  2.82E+01  2.82E+01  2.82E+01  2.62E+01  1.00E+01  6.60E-04  0.00E-01  0.00E-01
CD111M  0.00E-01  1.33E-08  1.33E-08  1.32E-08  1.30E-08  1.05E-08  1.23E-09  6.31E-19  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CD111   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PD112   0.00E-01  2.46E+01  2.45E+01  2.46E+01  2.46E+01  2.44E+01  2.25E+01  9.85E+00  2.57E-03  0.00E-01  0.00E-01  0.00E-01
AG112   0.00E-01  2.46E+01  2.46E+01  2.46E+01  2.46E+01  2.46E+01  2.41E+01  1.16E+01  3.03E-03  0.00E-01  0.00E-01  0.00E-01
CD112   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PD113   0.00E-01  2.11E+01  2.09E+01  1.94E+01  9.23E+00  5.59E-03  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
AG113M  0.00E-01  2.11E+00  2.11E+00  2.10E+00  1.64E+00  3.01E-03  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
AG113   0.00E-01  1.90E+01  1.90E+01  1.90E+01  1.89E+01  1.94E+01  1.32E+01  5.04E-01  3.13E-15  0.00E-01  0.00E-01  0.00E-01
CD113M  0.00E-01  2.66E-05  2.66E-05  2.66E-05  2.66E-05  2.66E-05  2.66E-05  2.66E-05  2.66E-05  2.62E-05  2.28E-05  5.55E-06
CD113   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
IN113   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PD114   0.00E-01  2.08E+01  2.07E+01  1.98E+01  1.29E+01  1.69E-01  2.60E-20  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
AG114   0.00E-01  2.11E+01  2.10E+01  2.04E+01  1.33E+01  1.75E-01  2.69E-20  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CD114   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
IN114M  0.00E-01  6.25E-10  6.25E-10  6.25E-10  6.25E-10  6.25E-10  6.24E-10  6.15E-10  5.33E-10  1.25E-10  6.73E-17  0.00E-01
IN114   0.00E-01  1.18E-09  1.17E-09  1.12E-09  8.22E-10  6.03E-10  6.02E-10  5.94E-10  5.14E-10  1.21E-10  6.49E-17  0.00E-01
SN114   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PD115   0.00E-01  1.91E+01  1.88E+01  1.64E+01  4.10E+00  3.91E-06  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
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233 DAYS OPERATION & 0 DAYS SHUTDOWN
POWER=   0.07MW. BURNUP=     22.MWD. FLUX= 1.50E+13N/CM**2-SEC

                                                 NUCLIDE RADIOACTIVITY, CURIES
                                             BASIS = 30.167KGOF FUEL 93%U-235 & 7%U-238
          CHARGE   DISCHARGE      1.SEC     10.SEC    100.SEC   1000.SEC  10000.SEC100000.SEC********SEC********SEC********SEC********SEC
AG1154   0.00E-01   5.35E+00   5.35E+00   5.23E+00   1.93E+00   1.97E-06   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
AG115    0.00E-01   1.56E+01   1.56E+01   1.55E+01   1.51E+01   9.05E+00   5.90E-02   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
CD1154   0.00E-01   1.39E+00   1.39E+00   1.39E+00   1.39E+00   1.39E+00   1.39E+00   1.37E+00   1.16E+00   2.15E-01   1.10E-09   0.00E-01
CD115    0.00E-01   1.95E+01   1.95E+01   1.95E+01   1.95E+01   1.95E+01   1.89E+01   1.37E+01   5.37E-01   4.61E-15   0.00E-01   0.00E-01
IN1154   0.00E-01   1.95E+01   1.95E+01   1.95E+01   1.95E+01   1.95E+01   1.94E+01   1.49E+01   5.87E-01   5.63E-15   0.00E-01   0.00E-01
IN115    0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
SN115    0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
AG116    0.00E-01   2.21E+01   2.20E+01   2.11E+01   1.39E+01   2.17E-01   1.89E-19   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
CD116    0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
IN1164   0.00E-01   2.07E-03   2.07E-03   2.06E-03   2.02E-03   1.67E-03   2.43E-04   1.06E-12   0.00E-01   0.00E-01   0.00E-01   0.00E-01
IN115    0.00E-01   5.95E-04   5.57E-04   3.57E-04   4.14E-06   1.84E-25   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
SN116    0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
AG117    0.00E-01   2.21E+01   2.19E+01   1.99E+01   7.74E+00   6.08E-04   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
CD1174   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
CD117    0.00E-01   2.34E+01   2.34E+01   2.34E+01   2.33E+01   2.17E+01   1.05E+01   7.72E-03   0.00E-01   0.00E-01   0.00E-01   0.00E-01
IN1174   0.00E-01   2.34E+01   2.34E+01   2.34E+01   2.34E+01   2.33E+01   1.82E+01   3.49E-02   0.00E-01   0.00E-01   0.00E-01   0.00E-01
IN117    0.00E-01   1.10E+01   1.10E+01   1.10E+01   1.10E+01   1.10E+01   9.62E+00   2.33E-02   0.00E-01   0.00E-01   0.00E-01   0.00E-01
SN1174   0.00E-01   2.08E-08   2.08E-08   2.08E-08   2.08E-08   2.07E-08   2.06E-08   1.96E-08   1.17E-09   6.74E-11   0.00E-01   0.00E-01
SN117    0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
CD118    0.00E-01   2.47E+01   2.46E+01   2.46E+01   2.41E+01   1.95E+01   2.33E+00   1.42E-09   0.00E-01   0.00E-01   0.00E-01   0.00E-01
IN1184   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
IN118    0.00E-01   2.47E+01   2.47E+01   2.46E+01   2.41E+01   1.95E+01   2.34E+00   1.43E-09   0.00E-01   0.00E-01   0.00E-01   0.00E-01
SN118    0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
CD1194   0.00E-01   1.17E+01   1.16E+01   1.12E+01   7.62E+00   1.62E-01   3.07E-18   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
CD119    0.00E-01   1.17E+01   1.17E+01   1.16E+01   1.04E+01   3.68E+00   1.12E-04   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
IN1194   0.00E-01   2.34E+01   2.34E+01   2.34E+01   2.32E+01   1.65E+01   6.53E-02   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
IN119    0.00E-01   1.17E+00   1.17E+00   1.17E+00   1.17E+00   8.97E-01   3.69E-03   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
SN1194   0.00E-01   3.26E-02   3.26E-02   3.26E-02   3.26E-02   3.26E-02   3.26E-02   3.25E-02   3.16E-02   2.37E-02   1.32E-03   3.77E-16
SN119    0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
CD120    0.00E-01   2.28E+01   2.25E+01   2.03E+01   7.17E+00   2.19E-04   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
IN1204   0.00E-01   1.14E+01   1.14E+01   1.06E+01   3.79E+00   1.16E-04   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
IN120    0.00E-01   1.26E+01   1.26E+01   1.23E+01   7.35E+00   4.59E-04   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
SN120    0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
CD121    0.00E-01   2.16E+01   2.15E+01   2.09E+01   1.55E+01   7.94E-01   9.98E-14   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
IN1214   0.00E-01   2.16E+01   2.16E+01   2.15E+01   2.05E+01   2.93E+00   8.63E-13   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
IN121    0.00E-01   3.08E+00   3.01E+00   2.45E+00   3.06E-01   2.85E-19   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
SN1214   0.00E-01   3.90E-09   3.90E-09   3.90E-09   3.90E-09   3.90E-09   3.90E-09   3.90E-09   3.89E-09   3.83E-09   3.78E-09   2.92E-09
SN121    0.00E-01   2.53E+01   2.53E+01   2.53E+01   2.52E+01   2.52E+01   2.36E+01   1.24E+01   2.03E-02   0.00E-01   0.00E-01   0.00E-01
SB121    0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
IN122    0.00E-01   2.44E-09   2.23E-08   1.02E-03   4.20E-12   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
SN122    0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
SB1224   0.00E-01   1.91E-05   1.91E-05   1.86E-05   1.45E-05   1.22E-06   2.17E-17   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
SB122    0.00E-01   1.91E-03   1.91E-03   1.91E-03   1.91E-03   1.91E-03   1.86E-03   1.44E-03   1.09E-04   6.89E-15   0.00E-01   0.00E-01
TE122    0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
IN1234   0.00E-01   2.65E+01   2.60E+01   2.19E+01   3.96E+00   1.15E-07   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
IN123    0.00E-01   2.65E+01   2.47E+01   1.32E+01   2.59E-02   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
SN1234   0.00E-01   3.14E+01   3.14E+01   3.14E+01   3.06E+01   2.36E+01   1.75E+00   9.03E-12   0.00E-01   0.00E-01   0.00E-01   0.00E-01
SN123    0.00E-01   2.13E+01   2.13E+01   2.13E+01   2.13E+01   2.13E+01   2.12E+01   2.11E+01   1.99E+01   1.12E+01   3.47E-02   0.00E-01
SB123    0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
TE1234   0.00E-01   5.00E-09   5.00E-09   5.00E-09   5.00E-09   5.00E-09   5.00E-09   4.97E-09   4.67E-09   2.52E-09   5.26E-12   0.00E-01
TE123    0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
IN124    0.00E-01   1.50E-09   1.26E-09   2.65E-10   4.47E-17   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
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233 DAYS OPERATION & 0 DAYS SHUTDOWN
POWER=   0.079MW, BURNUP=     22.MWD, FLUX= 1.50E+13N/CM**2-SEC

                                                        NUCLIDE RADIOACTIVITY, CURIES
                                                   BASIS = 30.167KGOF FUEL 93XU-235 & 7XU-238
            CHARGE   DISCHARGE      1.SEC    10.SEC   100.SEC  1000.SEC 10000.SEC100000.SEC*******SEC*******SEC*******SEC*******SEC
SN124     0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SB124M    0.00E-01  4.34E-05  4.31E-05  4.03E-05  2.06E-05  2.52E-08  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SB124     0.00E-01  7.71E-01  7.71E-01  7.71E-01  7.71E-01  7.70E-01  7.70E-01  7.60E-01  6.74E-01  2.02E-01  1.20E-06  0.00E-01
TE124     0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SN125M    0.00E-01  1.67E-04  1.67E-04  1.65E-04  1.48E-04  5.07E-05  1.12E-09  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SN125     0.00E-01  4.80E+01  4.80E+01  4.80E+01  4.80E+01  4.79E+01  4.76E+01  4.41E+01  2.04E+01  9.41E-03  0.00E-01  0.00E-01
SB125     0.00E-01  2.36E+01  2.36E+01  2.36E+01  2.36E+01  2.36E+01  2.36E+01  2.36E+01  2.37E+01  2.22E+01  1.07E+01  7.05E-03
TE125M    0.00E-01  6.74E+00  6.74E+00  6.74E+00  6.74E+00  6.74E+00  6.74E+00  6.77E+00  7.06E+00  8.37E+00  4.42E+00  2.92E-03
TE125     0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SN126     0.00E-01  1.02E-03  1.02E-03  1.02E-03  1.02E-03  1.02E-03  1.02E-03  1.02E-03  1.02E-03  1.02E-03  1.02E-03  1.02E-03
SB126M    0.00E-01  1.02E-03  1.02E-03  1.02E-03  1.02E-03  1.02E-03  1.02E-03  1.02E-03  1.02E-03  1.02E-03  1.02E-03  1.02E-03
SB126     0.00E-01  2.46E+01  2.46E+01  2.46E+01  2.46E+01  2.46E+01  2.44E+01  2.30E+01  1.29E+01  4.11E-02  1.01E-03  1.01E-03
TE126     0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SN127M    0.00E-01  1.05E+02  1.05E+02  1.02E+02  7.86E+01  5.84E+00  3.01E-11  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SN127     0.00E-01  1.05E+02  1.05E+02  1.05E+02  1.04E+02  9.57E+01  4.19E+01  1.09E-02  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SB127     0.00E-01  2.84E+02  2.84E+02  2.84E+02  2.84E+02  2.83E+02  2.79E+02  2.33E+02  3.61E+01  2.92E-07  0.00E-01  0.00E-01
TE127M    0.00E-01  5.16E+01  5.16E+01  5.16E+01  5.16E+01  5.16E+01  5.16E+01  5.16E+01  4.98E+01  2.53E+01  3.43E-02  0.00E-01
TE127     0.00E-01  2.78E+02  2.78E+02  2.78E+02  2.78E+02  2.78E+02  2.77E+02  2.50E+02  8.05E+01  2.55E+01  3.39E-02  0.00E-01
I127      0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SN128     0.00E-01  3.20E+02  3.20E+02  3.19E+02  3.14E+02  2.63E+02  4.51E+01  1.00E-06  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SB128M    0.00E-01  3.10E+02  3.10E+02  3.10E+02  3.10E+02  2.89E+02  5.38E+01  1.20E-06  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SB128     0.00E-01  1.14E+02  1.14E+02  1.14E+02  1.14E+02  1.12E+02  9.27E+01  1.35E+01  5.88E-08  0.00E-01  0.00E-01  0.00E-01
TE128     0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
 I128     0.00E-01  3.06E-02  3.06E-02  3.05E-02  2.92E-02  1.93E-02  3.02E-04  2.62E-22  0.00E-01  0.00E-01  0.00E-01  0.00E-01
XE128     0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SN129M    0.00E-01  2.21E+02  2.21E+02  2.21E+02  2.17E+02  1.83E+02  3.23E+01  9.62E-07  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SN129     0.00E-01  2.21E+02  2.21E+02  2.18E+02  1.95E+02  6.13E+01  5.90E-04  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SB129     0.00E-01  7.38E+02  7.38E+02  7.37E+02  7.36E+02  7.20E+02  5.10E+02  9.23E+00  2.91E-17  0.00E-01  0.00E-01  0.00E-01
TE129M    0.00E-01  1.17E+02  1.17E+02  1.17E+02  1.17E+02  1.17E+02  1.17E+02  1.15E+02  9.33E+01  1.12E+01  6.68E-09  0.00E-01
TE129     0.00E-01  7.56E+02  7.56E+02  7.56E+02  7.55E+02  7.46E+02  6.08E+02  8.45E+01  5.98E+01  7.15E+00  4.29E-09  0.00E-01
 I129     0.00E-01  2.55E-05  2.55E-05  2.55E-05  2.55E-05  2.55E-05  2.55E-05  2.55E-05  2.56E-05  2.61E-05  2.61E-05  2.61E-05
XE129M    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
XE129     0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SN130     0.00E-01  5.36E+02  5.34E+02  5.13E+02  3.44E+02  6.30E+00  2.71E-17  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SB130M    0.00E-01  4.82E+02  4.82E+02  4.82E+02  4.68E+02  1.44E+02  5.22E-05  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SB130     0.00E-01  6.25E+02  6.25E+02  6.23E+02  6.05E+02  4.44E+02  1.90E+01  3.95E-13  0.00E-01  0.00E-01  0.00E-01  0.00E-01
TE130     0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
 I130M    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
 I130     0.00E-01  3.76E+00  3.76E+00  3.75E+00  3.76E+00  3.71E+00  3.22E+00  7.97E-01  6.79E-07  0.00E-01  0.00E-01  0.00E-01
XE130     0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SN131     0.00E-01  7.66E+02  7.63E+02  7.40E+02  5.45E+02  2.56E+01  1.34E-12  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SB131     0.00E-01  1.63E+03  1.62E+03  1.62E+03  1.58E+03  1.06E+03  1.16E+01  2.70E-19  0.00E-01  0.00E-01  0.00E-01  0.00E-01
TE131M    0.00E-01  2.44E+02  2.44E+02  2.44E+02  2.44E+02  2.44E+02  2.32E+02  1.30E+02  4.03E-01  0.00E-01  0.00E-01  0.00E-01
TE131     0.00E-01  1.73E+03  1.73E+03  1.73E+03  1.72E+03  1.52E+03  1.15E+02  2.37E+01  7.36E-02  0.00E-01  0.00E-01  0.00E-01
 I131     0.00E-01  1.93E+03  1.93E+03  1.93E+03  1.93E+03  1.93E+03  1.92E+03  1.77E+03  7.32E+02  9.32E-02  0.00E-01  0.00E-01
XE131M    0.00E-01  1.55E+01  1.55E+01  1.55E+01  1.55E+01  1.55E+01  1.55E+01  1.54E+01  1.25E+01  5.35E-02  0.00E-01  0.00E-01
XE131     1.00E-01  0.00E-01  0.00E+01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SN132     0.00E-01  6.17E+02  6.13E+02  5.85E+02  3.65E+02  3.23E+00  9.67E-21  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SB132M    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SB132     0.00E-01  2.03E+03  2.02E+03  1.96E+03  1.37E+03  2.40E+01  1.98E-19  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
TE132     0.00E-01  3.02E+03  3.02E+03  3.02E+03  3.02E+03  3.01E+03  2.95E+03  2.36E+03  2.56E+02  5.75E-08  0.00E-01  0.00E-01
 I132     0.00E-01  3.02E+03  3.02E+03  3.02E+03  3.02E+03  3.02E+03  2.99E+03  2.41E+03  2.63E+02  5.92E-08  0.00E-01  0.00E-01
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233 DAYS OPERATION & 0 DAYS SHUTDOWN
POWER=    0.07MW, BURNUP=      22.MWD, FLUX= 1.60E+13N/CM**2-SEC

                                                  NUCLIDE RADIOACTIVITY, CURIES
                                               BASIS = 30.167KGOF FUEL 93%U-235 & 7%U-238
           CHARGE   DISCHARGE     1.SEC    10.SEC   100.SEC  1000.SEC 10000.SEC100000.SEC*******SEC*******SEC*******SEC*******SEC
XE132    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SB133    0.00E-01  2.09E+03  2.09E+03  2.04E+03  1.59E+03  1.34E+02  2.38E-09  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
TE133M   0.00E-01  1.51E+03  1.51E+03  1.51E+03  1.50E+03  1.30E+03  1.63E+02  1.52E-07  0.00E-01  0.00E-01  0.00E-01  0.00E-01
TE133    0.00E-01  2.80E+03  2.80E+03  2.78E+03  2.62E+03  1.32E+03  2.86E+01  2.64E-08  0.00E-01  0.00E-01  0.00E-01  0.00E-01
 I133    0.00E-01  4.12E+03  4.12E+03  4.12E+03  4.11E+03  4.11E+03  3.84E+03  1.63E+03  4.39E-01  0.00E-01  0.00E-01  0.00E-01
XE133M   0.00E-01  9.88E+01  9.88E+01  9.88E+01  9.88E+01  9.88E+01  9.87E+01  8.85E+01  4.67E+00  6.23E-14  0.00E-01  0.00E-01
XE133    0.00E-01  4.12E+03  4.12E+03  4.12E+03  4.12E+03  4.12E+03  4.11E+03  3.92E+03  1.10E+03  1.24E-03  0.00E-01  0.00E-01
CS133    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SB134    0.00E-01  9.88E+02  6.23E+02  9.73E+00  9.44E-18  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
TE134    0.00E-01  3.02E+03  3.02E+03  3.01E+03  2.94E+03  2.29E+03  1.93E+02  3.42E-09  0.00E-01  0.00E-01  0.00E-01  0.00E-01
 I134    0.00E-01  4.19E+03  4.19E+03  4.18E+03  4.16E+03  3.88E+03  1.04E+03  5.00E-16  0.00E-01  0.00E-01  0.00E-01  0.00E-01
XE134    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CS134M   0.00E-01  2.71E-02  2.71E-02  2.70E-02  2.69E-02  2.53E-02  1.39E-02  3.54E-05  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CS134    0.00E-01  3.95E-02  3.95E-02  3.93E-02  3.95E-02  3.93E-02  3.95E-02  3.93E-02  3.91E-02  3.55E-02  1.33E-02  8.73E-07
BA134    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
TE135    0.00E-01  2.09E+03  2.04E+03  1.65E+03  1.92E+02  8.72E-08  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
 I135    0.00E-01  3.69E+03  3.69E+03  3.69E+03  3.68E+03  3.59E+03  2.77E+03  2.39E+02  1.22E-09  0.00E-01  0.00E-01  0.00E-01
XE135M   0.00E-01  1.11E+03  1.11E+03  1.11E+03  1.11E+03  1.10E+03  8.65E+02  6.51E+01  3.81E-10  0.00E-01  0.00E-01  0.00E-01
XE135    0.00E-01  4.00E+03  4.00E+03  4.00E+03  4.00E+03  3.99E+03  3.85E+03  1.15E+03  1.14E-05  0.00E-01  0.00E-01  0.00E-01
CS135M   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CS135    0.00E-01  7.43E-04  7.43E-04  7.43E-04  7.43E-04  7.43E-04  7.43E-04  7.45E-04  7.45E-04  7.45E-04  7.45E-04  7.43E-04
BA135M   0.00E-01  2.11E-09  2.11E-09  2.11E-09  2.11E-09  2.10E-09  1.97E-09  1.08E-09  2.57E-12  0.00E-01  0.00E-01  0.00E-01
BA135    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
 I136    0.00E-01  2.45E-04  2.43E-04  2.25E-04  1.06E-04  5.79E-09  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
XE136    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CS136    0.00E-01  2.27E+02  2.27E+02  2.27E+02  2.27E+02  2.27E+02  2.26E+02  2.14E+02  1.23E+02  4.75E-01  0.00E-01  0.00E-01
BA136    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
 I137    0.00E-01  2.16E-13  2.15E-13  1.58E-13  3.55E-14  5.90E-26  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
XE137    0.00E-01  3.33E+03  3.32E+03  3.23E+03  2.47E+03  1.72E+02  4.55E-10  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CS137    0.00E-01  7.06E+01  7.06E+01  7.06E+01  7.06E+01  7.07E+01  7.06E+01  7.06E+01  7.06E+01  7.01E+01  6.57E+01  3.40E+01
BA137M   0.00E-01  6.61E+01  6.61E+01  6.61E+01  6.61E+01  6.61E+01  6.61E+01  6.61E+01  6.60E+01  6.55E+01  6.14E+01  3.13E+01
BA137    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
 I138    0.00E-01  1.08E-23  1.09E-23  1.09E-23  2.77E-28  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
XE138    0.00E-01  2.95E+03  2.95E+03  2.93E+03  2.76E+03  1.50E+03  3.31E+00  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CS138    0.00E-01  3.97E+03  3.97E+03  3.97E+03  3.93E+03  3.41E+03  1.98E+02  1.91E-12  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BA138    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
 I139    0.00E-01  5.57E-34  5.57E-34  5.57E-34  1.58E-47  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
XE139    0.00E-01  2.03E+03  2.00E+03  1.73E+03  4.05E+02  2.03E-04  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CS139    0.00E-01  3.45E+03  3.44E+03  3.43E+03  3.17E+03  1.07E+03  1.89E-02  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BA139    0.00E-01  3.75E+03  3.75E+03  3.75E+03  3.75E+03  3.53E+03  1.05E+03  3.75E-03  0.00E-01  0.00E-01  0.00E-01  0.00E-01
LA139    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
XE140    0.00E-01  1.29E+03  1.24E+03  8.38E+02  1.70E+01  1.98E-16  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CS140    0.00E-01  2.89E+03  2.87E+03  2.71E+03  1.15E+03  9.05E-02  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BA140    0.00E-01  3.51E+03  3.51E+03  3.51E+03  3.51E+03  3.50E+03  3.49E+03  3.29E+03  1.87E+03  6.65E+00  0.00E-01  0.00E-01
LA140    0.00E-01  3.52E+03  3.52E+03  3.52E+03  3.52E+03  3.52E+03  3.51E+03  3.47E+03  2.15E+03  7.65E+00  0.00E-01  0.00E-01
CE140    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
XE141    0.00E-01  7.41E+02  5.24E+02  2.32E+01  6.58E-13  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CS141    0.00E-01  2.52E+03  2.47E+03  1.94E+03  1.44E+02  7.42E-10  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BA141    0.00E-01  3.69E+03  3.69E+03  3.68E+03  3.51E+03  1.97E+03  6.12E+00  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
LA141    0.00E-01  3.88E+03  3.88E+03  3.88E+03  3.88E+03  3.82E+03  2.56E+03  3.01E+01  1.52E-18  0.00E-01  0.00E-01  0.00E-01
CE141    0.00E-01  3.86E+03  3.86E+03  3.86E+03  3.86E+03  3.85E+03  3.86E+03  3.79E+03  3.03E+03  3.26E+02  6.85E-08  0.00E-01
PR141    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
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293 DAYS OPERATION & 0 DAYS SHUTDOWN
POWER=   0.07MW, BURNUP=     22.MWD, FLUX= 1.60E+13N/CM**2-SEC

                                                     NUCLIDE RADIOACTIVITY, CURIES
                                                 BASIS = 30.167KGOF FUEL 93%U-235 & 7%U-238
           CHARGE  DISCHARGE     1.SEC     10.SEC    100.SEC  1000.SEC 10000.SEC100000.SEC********SEC********SEC********SEC********SEC
XE142    0.00E-01  3.21E+02  2.02E+02  3.16E+00  2.74E-18  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CS142    0.00E-01  1.72E+03  1.34E+03  1.08E+02  1.90E-10  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BA142    0.00E-01  3.20E+03  3.20E+03  3.19E+03  2.99E+03  1.12E+03  8.82E-02  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
LA142    0.00E-01  3.58E+03  3.58E+03  3.58E+03  3.58E+03  3.39E+03  1.15E+03  1.42E-02  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CE142    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PR142    0.00E-01  5.73E-02  5.73E-02  5.73E-02  5.72E-02  5.67E-02  5.18E-02  2.10E-02  2.53E-06  0.00E-01  0.00E-01  0.00E-01
ND142    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
XE143    0.00E-01  1.11E+02  5.55E+01  1.09E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CS143    0.00E-01  9.84E+02  7.19E+02  3.41E+01  9.72E-13  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
BA143    0.00E-01  2.65E+03  2.54E+03  1.60E+03  8.85E+00  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
LA143    0.00E-01  3.50E+03  3.50E+03  3.49E+03  3.26E+03  1.55E+03  9.25E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CE143    0.00E-01  3.57E+03  3.57E+03  3.57E+03  3.57E+03  3.55E+03  3.39E+03  2.00E+03  1.05E+01  0.00E-01  0.00E-01  0.00E-01
PR143    0.00E-01  3.48E+03  3.48E+03  3.49E+03  3.49E+03  3.49E+03  3.48E+03  3.44E+03  2.15E+03  1.11E+01  0.00E-01  0.00E-01
ND143    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
LA144    0.00E-01  2.95E+03  2.48E+03  5.22E+02  8.80E-05  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CE144    0.00E-01  1.62E+03  1.62E+03  1.62E+03  1.62E+03  1.62E+03  1.62E+03  1.61E+03  1.57E+03  1.22E+03  9.60E+01  8.72E-10
PR144    0.00E-01  1.62E+03  1.62E+03  1.62E+03  1.62E+03  1.62E+03  1.62E+03  1.61E+03  1.57E+03  1.22E+03  9.50E+01  8.72E-10
ND144    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CE145    0.00E-01  2.36E+03  2.36E+03  2.28E+03  1.61E+03  5.03E+01  4.47E-14  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PR145    0.00E-01  2.37E+03  2.37E+03  2.37E+03  2.37E+03  2.31E+03  1.73E+03  9.55E+01  2.49E-11  0.00E-01  0.00E-01  0.00E-01
ND145    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CE146    0.00E-01  1.78E+03  1.79E+03  1.77E+03  1.64E+03  7.81E+02  4.65E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PR146    0.00E-01  1.84E+03  1.84E+03  1.84E+03  1.84E+03  1.59E+03  3.46E+01  5.42E-18  0.00E-01  0.00E-01  0.00E-01  0.00E-01
ND146    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CE147    0.00E-01  1.29E+03  1.28E+03  1.16E+03  4.44E+02  3.02E-02  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PR147    0.00E-01  1.41E+03  1.41E+03  1.41E+03  1.36E+03  5.89E+02  1.02E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
ND147    0.00E-01  1.41E+03  1.41E+03  1.41E+03  1.41E+03  1.41E+03  1.40E+03  1.32E+03  6.87E+02  1.05E+00  0.00E-01  0.00E-01
PM147    0.00E-01  2.57E+02  2.57E+02  2.57E+02  2.57E+02  2.57E+02  2.57E+02  2.59E+02  2.63E+02  2.51E+02  1.19E+02  6.25E-02
SM147    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
CE148    0.00E-01  8.60E+02  8.47E+02  7.32E+02  1.72E+02  8.59E-05  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PR148    0.00E-01  1.06E+03  1.06E+03  1.05E+03  7.70E+02  4.79E+00  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
ND148    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01 -0.00E-01  0.00E-01  0.00E-01
PM148M   0.00E-01  1.61E-01  1.61E-01  1.61E-01  1.61E-01  1.61E-01  1.61E-01  1.58E-01  1.33E-01  2.39E-02  8.15E-10  0.00E-01
PM148    0.00E-01  1.98E-01  1.98E-01  1.98E-01  1.98E-01  1.97E-01  1.95E-01  1.72E-01  5.25E-02  1.91E-03  6.54E-11  0.00E-01
SM148    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PR149    0.00E-01  9.28E-06  9.24E-06  8.83E-06  5.62E-06  6.12E-08  1.43E-27  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
ND149    0.00E-01  7.09E+02  7.09E+02  7.09E+02  7.02E+02  6.37E+02  2.43E+02  1.60E-02  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PM149    0.00E-01  7.15E+02  7.15E+02  7.15E+02  7.15E+02  7.13E+02  7.05E+02  5.13E+02  1.97E+01  1.32E-13  0.00E-01  0.00E-01
SM149    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
ND150    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PM150    0.00E-01  2.34E+01  2.34E+01  2.33E+01  2.32E+01  2.18E+01  1.14E+01  1.87E-02  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SM150    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
ND151    0.00E-01  2.41E+02  2.41E+02  2.39E+02  2.19E+02  9.20E+01  1.59E-02  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PM151    0.00E-01  2.70E+02  2.70E+02  2.70E+02  2.70E+02  2.70E+02  2.54E+02  1.37E+02  2.81E-01  0.00E-01  0.00E-01  0.00E-01
SM151    0.00E-01  1.71E+00  1.71E+00  1.71E+00  1.71E+00  1.71E+00  1.71E+00  1.72E+00  1.72E+00  1.72E+00  1.68E+00  1.34E+00
EU151    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PM152    0.00E-01  1.89E+02  1.88E+02  1.85E+02  1.56E+02  2.75E+01  8.21E-07  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SM152    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
EU152M   0.00E-01  1.59E-04  1.59E-04  1.59E-04  1.58E-04  1.55E-04  1.29E-04  2.00E-05  1.62E-13  0.00E-01  0.00E-01  0.00E-01
EU152    0.00E-01  5.09E-06  5.09E-06  5.09E-06  5.09E-06  5.09E-06  5.09E-06  5.09E-06  5.08E-06  4.93E-06  4.24E-06  8.15E-07
GD152    0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
PM153    0.00E-01  7.44E-06  7.43E-06  7.29E-06  6.03E-06  9.11E-07  5.62E-15  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
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293 DAYS OPERATION & 0 DAYS SHUTDOWN
POWER=   0.07MW, BURNUP=     22.MWD, FLUX= 1.60E+13N/CM**2-SEC

                                                  NUCLIDE RADIOACTIVITY, CURIES
                                             BASIS = 30.167KGOF FUEL 93XU-235 & 7XU-238
         CHARGE  DISCHARGE     1.SEC    10.SEC   100.SEC  1000.SEC 10000.SEC100000.SEC*******SEC*******SEC*******SEC*******SEC
SM153   0.00E-01  1.29E+02  1.29E+02  1.29E+02  1.29E+02  1.29E+02  1.24E+02  9.58E+01  2.15E+00  2.09E-15  0.00E-01  0.00E-01
EU153   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
GD153   0.00E-01  3.76E-10  3.76E-10  3.76E-10  3.76E-10  3.76E-10  3.76E-10  3.75E-10  3.64E-10  2.70E-10  1.37E-11  1.51E-24
PM154   0.00E-01  5.49E+01  5.47E+01  5.24E+01  3.46E+01  5.41E-01  4.70E-19  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SM154   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
EU154   0.00E-01  9.43E-04  9.43E-04  9.43E-04  9.43E-04  9.43E-04  9.43E-04  9.42E-04  9.41E-04  9.31E-04  8.22E-04  2.39E-04
GD154   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SM155   0.00E-01  4.38E+01  4.38E+01  4.36E+01  4.16E+01  2.65E+01  2.88E-01  6.73E-21  0.00E-01  0.00E-01  0.00E-01  0.00E-01
EU155   0.00E-01  1.16E+01  1.16E+01  1.16E+01  1.16E+01  1.15E+01  1.16E+01  1.16E+01  1.14E+01  1.02E+01  3.44E+00  6.21E-05
GD155   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SM156   0.00E-01  1.48E+01  1.48E+01  1.48E+01  1.48E+01  1.45E+01  1.21E+01  1.91E+00  1.89E-08  0.00E-01  0.00E-01  0.00E-01
EU156   0.00E-01  1.54E+01  1.54E+01  1.54E+01  1.54E+01  1.54E+01  1.54E+01  1.49E+01  9.24E+00  7.50E-02  9.33E-23  0.00E-01
GD156   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
SM157   0.00E-01  9.26E+00  9.05E+00  7.35E+00  9.18E-01  8.56E-10  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
EU157   0.00E-01  1.05E+01  1.05E+01  1.05E+01  1.05E+01  1.04E+01  9.25E+00  2.96E+00  3.31E-05  0.00E-01  0.00E-01  0.00E-01
GD157   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
EU158   0.00E-01  5.06E+00  5.05E+00  5.04E+00  4.93E+00  3.93E+00  4.10E-01  6.27E-11  0.00E-01  0.00E-01  0.00E-01  0.00E-01
GD158   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
EU159   0.00E-01  2.10E+00  2.10E+00  2.09E+00  1.97E+00  1.10E+00  3.43E-03  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
GD159   0.00E-01  2.10E+00  2.10E+00  2.10E+00  2.10E+00  2.09E+00  1.92E+00  7.33E-01  4.83E-05  0.00E-01  0.00E-01  0.00E-01
TB159   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
EU160   0.00E-01  5.82E-03  5.79E-03  5.56E-03  3.67E-03  5.73E-05  4.98E-23  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
GD160   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
TB160   0.00E-01  4.96E-04  4.96E-04  4.96E-04  4.96E-04  4.96E-04  4.96E-04  4.91E-04  4.44E-04  1.03E-04  7.30E-09  0.00E-01
DY160   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
GD161   0.00E-01  2.85E-01  2.84E-01  2.75E-01  2.08E-01  1.25E-02  7.85E-15  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
TB161   0.00E-01  2.65E-01  2.85E-01  2.65E-01  2.85E-01  2.85E-01  2.82E-01  2.54E-01  8.91E-02  2.54E-06  0.00E-01  0.00E-01
DY161   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
GD162   0.00E-01  1.04E-09  1.04E-09  1.03E-09  9.32E-10  3.43E-10  1.56E-14  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
TB162M  0.00E-01  1.04E-09  1.04E-09  1.04E-09  1.03E-09  6.52E-10  5.54E-14  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
TB162   0.00E-01  2.80E-06  2.80E-06  2.80E-05  2.78E-06  2.57E-05  1.17E-06  4.43E-10  0.00E-01  0.00E-01  0.00E-01  0.00E-01
DY162   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
TB163M  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
TB163   0.00E-01  1.44E-12  1.44E-12  1.44E-12  1.44E-12  1.40E-12  1.07E-12  7.47E-14  1.97E-25  0.00E-01  0.00E-01  0.00E-01
DY163   0.00E-01  0.00E-01  0.00E-01  0.00E-01  1.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
TB164   0.00E-01  4.62E-19  4.62E-19  4.62E-19  4.62E-19  4.62E-19  4.62E-19  4.52E-19  2.47E-22  0.00E-01  0.00E-01  0.00E-01
DY164   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
DY165M  0.00E-01  6.57E-19  6.57E-19  6.57E-19  6.57E-19  1.71E-22  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
DY165   0.00E-01  2.63E-19  2.63E-19  2.63E-19  2.63E-19  2.63E-19  2.63E-19  1.48E-22  0.00E-01  0.00E-01  0.00E-01  0.00E-01
HO165   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
DY166   0.00E-01  2.84E-26  2.84E-26  2.84E-26  2.84E-26  2.84E-26  2.84E-26  2.64E-26  2.84E-25  1.65E-35  0.00E-01  0.00E-01
HO166M  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
HO166   0.00E-01  2.45E-23  2.45E-23  2.45E-23  2.45E-23  2.45E-23  2.45E-23  2.45E-23  2.45E-23  2.47E-35  0.00E-01  0.00E-01
ER166   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
ER167   0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01  0.00E-01
 TOTAL  0.00E-01  3.12E+05  3.07E+05  2.84E+05  2.39E+05  1.73E+05  1.14E+05  6.70E+04  3.37E+04  9.07E+03  6.40E+02  1.25E+02
```

```
                 PHOTON SPECTRUM AS A FUNCTION OF TIME FOR FISSION PRODUCTS


                                  293 DAYS OPERATION & 0 DAYS SHUTDOWN
                                         POWER=   0.07 MW, BURNUP=     22.MWD, FLUX= 1.60E+13 N**2-SEC

                                             TWELVE GROUP PHOTON RELEASE RATES, PHOTONS/SEC
                                                  BASIS = 30.167KGOF FUEL 93%U-235 & 7%U-238
             EMEAN                                     TIME AFTER DISCHARGE
   (MEV)      INITIAL      1.SEC     10.SEC    100.SEC   1000.SEC 10000.SEC100000.SEC*******SEC*******SEC*******SEC*******SEC
 3.00E-01   2.09E+15   2.07E+15   2.01E+15   1.75E+15   1.12E+15   6.13E+14   3.61E+14   1.01E+14   1.17E+13   1.03E+12   7.11E+10
 6.30E-01   4.29E+15   4.28E+15   4.24E+15   3.94E+15   3.03E+15   1.92E+15   1.12E+15   5.16E+14   1.55E+14   3.21E+12   1.25E+12
 1.10E+00   1.61E+15   1.60E+15   1.51E+15   1.32E+15   8.18E+14   2.95E+14   8.84E+13   1.63E+13   9.51E+11   9.12E+10   2.65E+09
 1.55E+00   9.21E+14   9.18E+14   6.91E+14   7.10E+14   4.21E+14   2.07E+14   1.41E+14   8.02E+13   5.06E+11   2.18E+10   4.81E+08
 1.99E+00   1.79E+14   1.79E+14   1.74E+14   1.55E+14   1.05E+14   4.28E+13   5.07E+12   8.30E+11   3.93E+11   3.19E+10   1.45E+07
 2.38E+00   2.06E+14   2.06E+14   2.04E+14   1.93E+14   1.44E+14   3.71E+13   4.16E+12   2.56E+12   2.37E+10   1.94E+09   5.13E+00
 2.75E+00   7.57E+13   7.51E+13   7.02E+13   5.35E+13   3.04E+13   5.48E+12   3.73E+09   1.26E+09   1.03E+09   1.43E+09   4.04E-01
 3.25E+00   8.59E+13   8.68E+13   8.63E+13   8.01E+13   4.07E+13   3.24E+12   7.79E+07   3.91E+07   3.21E+07   4.43E+05   1.28E-02
 3.70E+00   1.04E+13   1.04E+13   1.03E+13   9.08E+12   3.29E+12   6.44E+10   5.93E-04   0.00E-01   0.00E-01   0.00E-01   0.00E-01
 4.22E+00   3.32E+13   3.32E+13   3.29E+13   2.53E+13   7.38E+11   1.99E-04   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
 4.70E+00   5.78E+12   5.78E+12   5.72E+12   4.49E+12   1.29E+11   1.58E+02   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
 5.25E+00   4.68E+12   4.68E+12   4.63E+12   3.64E+12   1.04E+11   2.80E-05   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01

              TOTAL  9.50E+15   9.47E+15   9.23E+15   8.22E+15   5.71E+15   3.12E+15   1.72E+15   7.17E+14   1.69E+14   4.38E+12   1.33E+12

            MEV/SEC  8.09E+15   8.06E+15   7.84E+15   6.90E+15   4.59E+15   2.24E+15   1.15E+15   5.06E+14   1.04E+14   2.53E+12   3.15E+11

                                             TWELVE GROUP ENERGY RELEASE RATES, MEV/WATT-SEC
                                                  BASIS = 30.167KGOF FUEL 93%U-235 & 7%U-238
             EMEAN                                     TIME AFTER DISCHARGE
   (MEV)      INITIAL      1.SEC     10.SEC    100.SEC   1000.SEC 10000.SEC100000.SEC*******SEC*******SEC*******SEC*******SEC
 3.00E-01   8.32E+09   8.26E+09   8.03E+09   6.94E+09   4.49E+09   2.45E+09   1.44E+09   4.04E+08   4.69E+07   4.11E+06   2.84E+05
 6.30E-01   3.60E+10   3.60E+10   3.56E+10   3.31E+10   2.54E+10   1.61E+10   9.43E+09   4.34E+09   1.30E+09   2.69E+07   1.05E+07
 1.10E+00   2.56E+10   2.34E+10   2.21E+10   1.93E+10   1.20E+10   4.32E+09   1.30E+09   2.39E+08   1.40E+07   1.34E+06   3.89E+04
 1.55E+00   1.90E+10   1.90E+10   1.84E+10   1.47E+10   8.70E+09   4.28E+09   2.90E+09   1.66E+09   1.05E+07   4.51E+05   9.95E+03
 1.99E+00   4.75E+09   4.74E+09   4.61E+09   4.13E+09   2.77E+09   1.14E+09   1.34E+08   2.20E+07   1.04E+07   8.47E+05   3.93E+02
 2.38E+00   6.55E+09   6.54E+09   6.46E+09   6.02E+09   4.57E+09   1.18E+09   1.32E+06   8.14E+07   7.52E+05   6.15E+04   1.63E-04
 2.75E+00   2.70E+09   2.75E+09   2.58E+09   1.95E+09   1.12E+09   2.01E+08   1.37E+05   4.61E+04   3.78E+04   5.25E+03   1.48E-05
 3.25E+00   3.77E+09   3.76E+09   3.74E+09   3.47E+09   1.76E+09   1.40E+08   3.38E+03   1.69E+03   1.39E+03   1.93E+02   5.56E-07
 3.70E+00   5.13E+08   5.13E+08   5.10E+08   4.48E+08   1.62E+08   3.18E+06   1.94E-09   0.00E-01   0.00E-01   0.00E-01   0.00E-01
 4.22E+00   1.87E+09   1.87E+09   1.85E+09   1.43E+09   4.15E+07   1.12E-09   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
 4.70E+00   3.62E+08   3.62E+08   3.59E+08   2.82E+08   8.05E+06   9.90E-03   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01
 5.25E+00   3.28E+08   3.27E+08   3.24E+08   2.55E+08   7.28E+06   1.96E-09   0.00E-01   0.00E-01   0.00E-01   0.00E-01   0.00E-01

              TOTAL  1.08E+11   1.08E+11   1.05E+11   9.20E+10   6.11E+10   2.98E+10   1.55E+10   6.74E+09   1.39E+09   3.37E+07   1.09E+07

        GAMMA WATTS  1.30E+03   1.29E+03   1.26E+03   1.11E+03   7.54E+02   3.59E+02   1.85E+02   8.11E+01   1.67E+01   4.96E-01   1.31E-01
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Appendix B

Radiological Risk Analysis Methodology

Appendix B
Radiological Risk Analysis Methodology

B.1 Introduction

The accident scenarios considered in Sections 3.0 result in a radiological risk to the general population. Accident scenarios that could release fuel include 1) land impact, 2) reentry heating, and 3) ocean impact. Fuel released under these conditions would be dispersed into the environment (air, water, and soil) and interact with the general population through various exposure pathways leading to inhalation, ingestion, and external radiological doses. Additionally, intact or dispersed reactor parts containing fuel or radioactive structure produce external radiation exposure as could a reactor criticality accident. The methodology used in evaluating the radiological risk associated with the missions considered in this Appendix is summarized in this section and described in detail in Reference 1.

The evaluation of the radiological impact of postulated scenarios involving fuel releases into the environment include the following steps:

1. Identification of postulated accident release modes, including the probability of release and the release location.

2. Source term definition, including the amount of each radionuclide released and the corresponding chemical form and particle size distribution.

3. An analysis of the dispersion and time behavior of the released radioactivity to determine the concentrations in environmental median (air, soil, and water) as a function of time.

4. An analysis of ingestion, inhalation and external radiological doses through each environmental exposure pathway.

5. An evaluation of the radiological impact in terms of the population doses received and the resulting health effects.

These steps in the analysis are described further in detail below.

B.2 Accident Scenarios and Source Term Definition

The accident scenarios, probabilities, and associated source terms for each mission are developed based on reference mission design data in the literature and analysis.

The specific activity of each radionuclide in the fuel at the time of initial release has been evaluated using the ORIGEN code. (Reference 2) The operating history of reactor systems is accounted for in arriving at the source term radionuclide spectrum at the time of release. To account for long term behavior of released fuel in the environment, specific activities were also calculated for time steps from 10^2 second to 10^{11} seconds following release.

B.3 Environmental Radioactive Concentrations

Environmental radioactive concentrations have been calculated as a function of time for the following type of releases:

- High altitude vapor releases
- High altitude particulate releases
- Low altitude (including ground level) releases
- Aquatic releases.

In order to account for the radiological impact over long time periods, the concentrations due to a given release were calculated in ten time steps ranging from 10^2 to 10^{11} seconds. Furthermore, the evaluation of environmental concentrations was performed initially on a fuel mass basis due to the large number of radionuclides of interest. Mass concentration was then converted to radioactivity concentration of each radionuclide by applying the time dependent specific activity factors generated as described in Section B.2.

In evaluating environmental transfer processes, consideration is given to interaction statistics. That is, for a given release scenario, the regional environment is described so that the interaction between the source terms and the environment can be evaluated. Interaction statistics for a given release scenario would include information such as the distribution of land, fresh water, ocean, population, and food supplies in the region that is expected to be affected by the release. General information of this nature is presented in the Overall Safety Manual, Volumes 2 and 3. (Reference 3)

B.3.1 High Altitude Vapor Releases

High altitude vapor releases result from partial or complete burnup due to reentry heating. The transport of such vapor is governed primarily by worldwide atmospheric circulation patterns. The atmosphere can be divided into three compartments: the mesophere (45 km altitude), the stratosphere (10 - 45 km), and the troposphere (0 - 10 km). Transport between these atmospheric compartments has been described in an approximate manner by an exponential box model, analogous to radioactive decay, in which a residence half-life is assigned to each compartment. (Reference 1) The residence half-lives are based on fallout data derived from nuclear weapons testing. Latitudinal variation of the ground level activity derived from the high altitude release at a given latitude is also based on nuclear weapons fallout data.

For high altitude vapor releases at a given latitude, the model predicts the normalized ground plane and airborne concentrations as a function of latitude and time after release.

B.3.2 High Altitude Particulate Releases

High altitude particulate releases can occur under the same conditions that result in high altitude vapor releases described above. The resulting particulates will follow trajectories to the Earth's surface that are determined by the mass, size, and shape of each particle, the release altitude, as well as the winds and density profile of the atmosphere.

The atmospheric dispersion of such particulate released at high altitudes has been described in Reference 1. In this model, the trajectories of individual mass elements are determined based on the rate of change of latitude, longitude and altitude during local wind speed components and the terminal fall velocity of the particles. A particle size distribution was used that is typical of fractured fuel.

Inputting the release altitude and latitude, the model predicts the ground plant concentration as a function of affected area. Resuspension and weathering of ground plane deposition is accounted for outside of the model.

B.3.3 Low Altitude Releases

Low altitude dispersion of fuel can result from 1) ground level releases following land impact or 2) resuspension of activity previously deposited derived from both high and low altitude releases.

Radiological doses to the general population due to low altitude releases must account for vanishingly small concentrations at great distances from the point of impact because such concentrations are important when a linear dose response model is used. A model is used in calculating population dose in which all released activity is accounted for in an average concentration calculation. (Reference 1)

B.3.4 Aquatic Releases

Aquatic transfer processes include the interaction of airborne dispersed activity and intact sources with water bodies. These interactions include fuel dissolution, transfers to sediment, and concurrent covering of intact sources by sedimentation and encrustation.

Average aquatic concentrations were calculated as a function of time for the ten discrete time steps mentioned previously. The average concentrations were calculated based on reference volumes required to produce annual fish/seafood and drinking water to persons within the affected fallout area, accounting for the land/water fraction within the area.

B.3.5 Environmental Concentration Outputs

The outputs of the environmental concentration models and interaction statistics described above include the following information for ten time steps centered from 10^2 to 10^{11} seconds following the accident:

- Normalized airborne concentration ($g/m^3/g$ released)
- Normalized ground concentration ($g/m^2/g$ released)
- Normalized vegetation concentration (g/m^2 leaf area/g released)
- Normalized aquatic concentration ($g/m^3/g$ released)
- Total grams of fuel released
- Number of persons affected.

These results serve as input to the radiological dose calculations described in the next section.

B.4 Radiological Dose, Health Effects, and Risk

Maximum individual and population doses were calculated for both dispersed fuel and intact source as described below.

B.4.1 Radiological Doses (Dispersed Fuel)

Radiological doses due to dispersed fuel were calculated in discrete time steps following the release using an inputs the results of the environmental concentration calculations described in the previous section. A computer code, TDOS, as developed by NUS to evaluate the doses in discrete time steps using the dose methodology presented in NRC Regulatory Guide 1.109. (Reference 4) For individual and population exposures during each time step, the resulting 50- year integrated dose commitments were evaluated for the following pathways:

- Inhalation
- Cloud immersion
- Ground plane radiation
- Vegetation ingestion
- Meat ingestion
- Milk ingestion
- Water ingestion
- Aquatic foods ingestion

Resulting health effects, evaluated as described in Section G.5.4 are also calculated by TDOS. (Reference 5)

The TDOS code output includes the following:

- User supplied input parametrics

- User supplied activities by nuclide and time

- Dose factor library

- Bio-transfer factors

- Dose or health effects by nuclide, time, organ, and pathway

- Environmental dose commitments and health effects for the first year, first 100 years, and the total for all time periods.

B.4.2 Radiological Doses (Intact Sources)

Radiological doses due to external radiation from intact sources have been evaluated using standard methods. The intact sources were treated as point sources with radiation fields attenuated inversely as the square of the distance and by absorption. Buildup in the air media and interactions at the air/ground interface were accounted for in a limited manner.

B.4.3 Radiological Health Effects

Health effects will be associated with radiological doses resulting from dispersed fuel and intact sources. A linear dose response model was used in evaluating long term population effects based on the NAS-NRC Committee on the Biological Effects of Ionizing Radiation (BEIR) as presented in the BEIR III report. (Reference 6) The linear dose response model assumes the health effects, in terms of excess cancer fatalities, are proportional to the dose, even for vanishingly small doses. Excess cancer fatalities in this case means those that would occur in addition to the normal incidence of cancer fatalities. The risk analysis presented in this report uses a central estimate of 120 cancer fatalities per million person-rem based on BERI-III.

B.4.4 References

1. Bartram, B. W. and D. K. Dougherty, A Long Term Radiological Risk Model for Plutonium-Fueled and Fission Reactor Space Nuclear Systems, Prepared for U.S. Department of Energy by NUS Corporation, NUS-3845 (June 30, 1981).

2. Oak Ridge National Laboratory, ORIGEN, Isotope Generation and Depletion Code-Matrix Exponential Method, CCC-217 (1976).

3. NUS Corporation, Overall Safety Manual, Prepared for U.S. Department of Energy (Updated for DOE through 1982).

4. U.S. Nuclear Regulatory Commission, Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluation Compliance with 10CFR50, USNRC Regulatory Guide 1.109, Rev.1(October 1977).

5. Bartram, B. W. and D. K. Dougherty, and S. R. Tamara, TDOS Computer Code User's Manual, NUS Corporation, NUS- 3851 (June 30, 1981).

6. National Academy of Sciences - National Research Council,Committee on the Biological Effects of Ionizing Radiation (BEIR III), The Effects on Populations of Exposures to Low Levels of Ionizing Radiation (1980).

INSERT FOR THE RECORD

☐	HOUSE	APPROPRIATIONS COMMITTEE	☐	HOUSE	ARMED SERVICES COMMITTEE	☐	HOUSE	OTHER
☐	SENATE		☐	SENATE		☐	SENATE	

HEARING DATE SEPT ~~16~~ 13,1988	TRANSCRIPT PAGE NO.	LINE NO.	INSERT NO.	Question 1

SENATOR JOHNSTON: If SDIO were to use nuclear reactors in orbit, do you anticipate that all would be confined to "nuclear safe" orbits, that is, orbits whose decay time is measured in centuries so that the radioactivity would diminish to acceptable levels before the satellite re-entered the Earth's atmosphere? If not please discuss the types of activities that involve nuclear reactors that would not be placed in nuclear safe orbits.

COLONEL HESS: SDIO missions in the post year 2000 time frame that might use nuclear reactors would, because of survivability considerations, be in orbits whose decay times are measured in centuries. In addition, electric propulsion might be used for orbit raising with a significant saving in launch mass. The potential use of reactors as a power source for electric propulsion could result in the initial reactor operation at an altitude whose decay time is not measured in centuries. As the reactor operating time increases, the orbital altitude increases; this results in progressively longer orbital lifetimes. The duration of operating time below altitudes that last for centuries would be such that the radioactivity build up is limited. In fact, an unplanned termination of thrust prior to reaching operational orbits might result in little radioactivity difference at the time of reentry into the earth's biosphere than that from long term decay at "nuclear safe" orbits.

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☐ HOUSE ☐ SENATE	APPROPRIATIONS COMMITTEE	☐ HOUSE ☐ SENATE	ARMED SERVICES COMMITTEE	☐ HOUSE ☐ SENATE	OTHER
HEARING DATE SEPT ~~16~~ 13, 1988	TRANSCRIPT PAGE NO.	LINE NO.	INSERT NO.		QUESTION 2

SENATOR JOHNSTON: Mr. Dave Buden of SDIO's space power program was quoted by SDI Monitor on August 8, 1988, as stating at the Inter-society Energy Conversion and Engineering Conference, "The success of SDI depends on a multimegawatt program and that probably means nuclear." Is it "probable" that SDI will require nuclear reactors in orbit?

COLONEL HESS: There are currently no nuclear-reactor powered systems in the Defense Acquisition Board (DAB) approved Phase I architecture. Follow-on phases of the program are being studied as are many system concepts. Several of these system concepts envision the use of large directed energy and/or advanced kinetic-energy weapons, e.g., hypervelocity guns. Many of these systems will require megawatts of burst power. The SDIO Megawatt Power program must succeed if these systems are to be technically and economically feasible and we are investing in both nuclear and non-nuclear approaches to the problem. It is too early to tell whether or not nuclear power systems will be the preferred solution. However, if nuclear systems are the clear technical and economic choice, they will be reflected in future SDS architectures.

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☐	SENATE		☐	SENATE		☐	SENATE	

HEARING DATE	TRANSCRIPT PAGE NO.	LINE NO.	INSERT NO.	
SEPT ~~16~~ 13, 1988				QUESTION 3

SENATOR JOHNSTON: In his prepared statement to the Committee, Academician Roald Sagdeev stated, "Space reactors could provide potential violators the opportunity to conceal nuclear warheads in space." Do you agree with this statement and if not, why?

COLONEL HESS: No. Since nuclear warheads do not emit discernable amounts of radiation, having a reactor on board does not appreciably change the opportunity to conceal nuclear warheads on orbit. On the contrary, the radiation from an operating reactor could cause neutron reactions within any concealed nuclear warheads and thus reveal their presence.

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☐	SENATE		☐	SENATE		☐	SENATE	
HEARING DATE SEPT ~~16~~ 13, 1988		TRANSCRIPT PAGE NO.		LINE NO.		INSERT NO.		Question 1

SENATOR MCCLURE: What impact would a total ban of space nuclear power have on the ability of this nation to deploy an effective SDI program?

COLONEL HESS: Space nuclear power provides the capability to deploy strategic defense system satellites that are more survivable, lighter weight, more maneuverable, and cost less. Thus the loss of nuclear option will result in the need to configure follow-on phase of SDS to use more satellites for survivability, use more expensive chemical propulsion for orbit raising, use very large solar arrays for baseload power, and use chemical power for burst power. The nuclear option is a significant one for SDI, and more importantly, the rest of DoD and NASA.

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☐	HOUSE	APPROPRIATIONS COMMITTEE	☐	HOUSE	ARMED SERVICES COMMITTEE	☐	HOUSE	OTHER
☐	SENATE		☐	SENATE		☐	SENATE	

HEARING DATE SEPT ~~16~~ 13, 88	TRANSCRIPT PAGE NO.	LINE NO.	INSERT NO.	QUESTION 2

SENATOR MC CLURE: If a complete ban on space nuclear power went into effect, who in your view, would suffer the most in terms of national security.

COLONEL HESS: In my view, the U.S. would lose the most.

INSERT FOR THE RECORD

☐ HOUSE ☐ SENATE	APPROPRIATIONS COMMITTEE	☐ HOUSE ☐ SENATE ARMED SERVICES COMMITTEE	☐ HOUSE ☐ SENATE	OTHER
HEARING DATE SEPT 13, 1988	TRANSCRIPT PAGE NO.	LINE NO.	INSERT NO.	QUESTION 3

SENATOR MC CLURE : Last January at the University of New Mexico Symposium, Senator Johnston expressed the opinion that the safety of reactors in space is Mankind's problem. In light of your discussions on SIREN, do you feel that this might form a basis for international cooperation?

COLONEL HESS: We have not seriously considered the matter of international cooperation, so at this time DoD is unable to give a meaningful response.

INSERT FOR THE RECORD

☐ HOUSE ☐ SENATE	APPROPRIATIONS COMMITTEE	☐ HOUSE ☐ SENATE	ARMED SERVICES COMMITTEE	☐ HOUSE ☐ SENATE	OTHER
HEARING DATE SEPT ~~16~~ 13, 1988	TRANSCRIPT PAGE NO.	LINE NO.	INSERT NO.		QUESTION 4

SENATOR MC CLURE: If space nuclear capabilities are not available, are there foreseeable military missions that would be eliminated?

COLONEL HESS: Survivable solar power systems could be used to a few tens of kilowatts. Thus, military missions would become confined to this level. The trend in power needs for military missions, with or without SDI, is increasing over time and will eventually exceed the levels projected for feasible survivable solar power systems. This includes potential missions like space-based radars, orbit transfer vehicles, hardened communications, arms control monitoring, post-attack assessment, and weapons platforms.

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Reply to Attn of XC:MDD:X88-00876f

DEC 7 1988

Mr. Jim Bruce
Senior Counsel
Committee on Energy
and Natural Resources
United States Senate
Washington, DC 20510

Dear Mr. Bruce:

Enclosed are the final responses to written questions submitted by Chrm. Johnston and Sen. McClure resulting from the September 13, 1988, hearing at which Dr. Robert Rosen testified on "Cosmos 1900 and the Future of Space Nuclear Power".

This material completes the information requested during that hearing.

Sincerely,

Mary D. Kerwin

Mary D. Kerwin
Director, Congressional
Liaison Division

Enclosures

COSMOS 1900 & THE FUTURE OF SPACE NUCLEAR POWER

Question 1: In his prepared statement to the Committee, Academician Roald Sagdeev said that the Space Research Institute of the USSR Academy of Sciences was unable to find any possible future scientific missions in near and deep space for at least 15 years which could not be carried out without the use of nuclear power. He added that it appears that even the manned mission to Mars can technically be realized effectively using non-nuclear sources of energy.

Does NASA agree with this assessment? If not, what missions would require nuclear power over the next 15 years?

Answer 1: NASA does not agree that Academician Sagdeev's assessment applies to the solar system exploration program of the United States. It is important to note that only the United States has conducted successful missions to the outer planets. These missions, Pioneer 10 and 11 and Voyagers 1 and 2, were enabled through the use of radioisotope thermoelectric generators (RTGs). No other power system options could meet the exacting mission requirements for low mass, compact volume, and highly reliable power systems. These nuclear power systems continue to operate after 15 years for the Pioneers and a decade for the Voyagers.

Planned missions to the outer planets such as Galileo (1989), Ulysses (1990), and others, all rely on RTGs for safe, reliable power generation. Indeed, all future outer planet missions (i.e., beyond Mars) are, at this time, expected to require RTGs to power the spacecraft systems. In addition, the favorable lightweight and compact features of RTGs make them highly desirable power generation options for future advanced robotic mobility systems to explore planet surfaces. Thus, NASA most certainly sees requirements for RTGs from now until well into the next century.

An Apollo-type manned mission to Mars, as represented by short stay, small crew size and limited exploratory capability characteristics, is technically feasible using non-nuclear sources of energy as noted by Academician Sagdeev. But future potential manned missions being studied by NASA to meet the U.S. goals of expanding our human presence and activities beyond Earth and of advancing scientific knowledge of the solar system, include sustained manned operations on the lunar surface and long duration exploration voyages.

Nuclear power plays a pivotal role in meeting these mission requirements. Mission operations on planetary surfaces dedicated to greatly extended scientific investigations, on-site resource evaluations and processing activities, extended human habitat and manned surface survey operations require reliable, high power sources capable of generating continuously, hundreds of kilowatts of electrical power. Availability of nuclear reactor power systems technology becomes a mission-enabling factor for any extensive surface operations at base sites with long night periods (e.g., a two-week lunar night cycle) as we had discussed in NASA's 13 September testimony to the Committee.

COSMOS 1900 & THE FUTURE OF SPACE NUCLEAR POWER

Question 1: As you know, it has been suggested that nuclear reactors be banned from earth orbit. Please comment on what impact, if any, such a ban might have on your agency's proposed missions.

Answer 1: Future mission studies being conducted by NASA encompass human and robotic solar system exploration activities, lunar operations, and earth-oriented applications. Prerequisite requirements have been identified for power sources with capacities and duty cycles far exceeding today's capabilities. Compared to chemical and solar systems, reactor power systems offer a viable approach to satisfying these future mission goals and specific power needs, both as a direct power source and as the power source for high performance electric propulsion systems needed for exploration of outer planets. A significant number of the potential U.S. civil space exploration missions would be enabled by the application of nuclear reactor power systems, while the operations of many others would be significantly enhanced by the use of compact, long-life, high performance reactor power systems.

Banning nuclear reactors from earth orbit will significantly foreclose the mission operations foreseen in these studies. For earth escape missions to lunar or planetary destinations, the assembled mission spacecraft and its inspace propulsion systems would be launched from the earth's surface to an earth parking orbit or via the direct injection escape mode. The capability for on-orbit assembly and check-out in earth orbit of future potential lunar and planetary spacecraft will be necessary for such missions. The impact of an earth orbit ban on proposed U.S. endeavors in space will be several-fold. First, the ban could foreclose nuclear-electric propulsion operations for the robotic, long duration and more distant solar system exploration missions which are of major scientific interest. The ban could similarly impact potential larger-scale human expeditions beyond earth and severely curtail future potential mission operations by limiting power availability for space logistics support, whether for surface operations or for in transit operations. The application of nuclear-powered high performance electric propulsion systems for effective interplanetary cargo transfer operations will be key elements in the successes of these future civil space endeavors. Sustained, low earth orbit operations can also be of significant future interest to the Nation in the area of space-based materials processing facilities that exploit the highly advantageous microgravity conditions of space. At some point in time the potential for large-scale commercial activities in the microgravity environment will be realized, and when it is, large amounts of electrical power that can be delivered by a nuclear reactor will be important to support such operations.

We believe that once space nuclear reactor power operations have been demonstrated and have been accepted by advanced missions planners, the potential for even broader civil space applications will emerge. Successful high capacity reactor power technology developments will support future national decisions on solar system exploration missions and will greatly extend the U.S.'s space operational capabilities.

COMMITTEE TO BRIDGE THE GAP
1637 BUTLER AVENUE, SUITE 203
LOS ANGELES, CALIFORNIA 90025
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October 31, 1988

Senator J. Bennett Johnston
Chairman
Committee on Energy and Natural Resources
United States Senate
Washington, D.C. 20510

Dear Chairman Johnston:

Enclosed please find my responses to the additional questions from the September 13 hearing on "Cosmos 1900 and the Future of Space Nuclear Power."

In my testimony at the hearing, I criticized the Department of Energy for not releasing a technical report on public health consequences of various generic space nuclear power accidents. I continue to believe that the withholding of this and other accident consequence documents is unwarranted and detrimental to the decision-making process.

But I would also like to acknowledge that DOE's space reactor program has faithfully responded to dozens of my Freedom of Information Act requests and other informal requests for information and assistance. Further, I have been a welcome guest at industry symposia and SP-100 Project Integration Meetings. In general, DOE has exhibited a high degree of professional courtesy for which I am grateful.

Finally, I would like to thank you and the Committee for holding the September 13 hearing, and for allowing me the privilege of participating in it.

Sincerely,

Steven Aftergood

Steven Aftergood
Executive Director

ADDITIONAL QUESTIONS FROM SENATOR McCLURE

Q1. Dr. Rosen of NASA has stated in his testimony that nuclear power is necessary for space exploration and expanding U.S. activities in space. Would you advocate limiting U.S. space activity efforts to avoid the use of nuclear power?

A1. The majority of NASA applications of space nuclear power contemplated for the next century are for missions beyond geosynchronous orbit, e.g. lunar and Mars bases, deep space propulsion systems, planetary probes, etc. We have no objection in principle to such missions.

The ban on nuclear power in Earth orbit proposed by U.S. and Soviet scientists was deliberately crafted so as not to interfere with NASA s deep space exploratory missions.

Q2. Would you support the use of nuclear reactors in Earth orbit if it was beneficial to support treaty verification through surveillance spacecraft?

A2. There is no power requirement for treaty verification surveillance purposes that cannot be met without the use of nuclear reactors. We would therefore favor the use of non-nuclear power supplies for surveillance spacecraft.

Q3. The Soviets have a long history of using nuclear reactors in Earth orbit, and will probably continue to do so. Do you propose that the U.S. should unilaterally ban reactors from Earth orbit?

A3. We do not propose that the U.S. unilaterally ban reactors from Earth orbit.

Rather, we favor a U.S. initiative to bring about an international ban. Since only the Soviet Union currently uses nuclear power in orbit, it is Soviet policy that would most immediately and directly be affected by such a ban.

We are encouraged to believe that an international ban is a realistic possibility by the Statement of Academician Sagdeev to the Committee, and by the attitudes of Soviet officials expressed to Daniel Hirsch and described in his testimony in this hearing.

Q4. Mr. Aftergood, you have previously stated that you believe that U.S. space reactor operation is acceptable in orbits of greater than 300 year duration. Why do you now believe that reactors should be banned from all Earth orbits?

A4. I have previously stated that deployment in a nuclear safe orbit (greater than 300 years) would eliminate the possibility of a Cosmos 954-type early reentry accident. I still believe that this is true, and that the nuclear safe orbit is a minimal safety standard that should not have been abandoned by the U.S. space reactor program.

However, even those nuclear powered satellites that are safely deployed or boosted into a stable, nuclear safe orbit present certain hazards. According to Nicholas L. Johnson and Darren S. McKnight, most such satellites reside in those parts of near-Earth space that are most densely populated with space debris (Artifical Space Debris, Orbit Books, 1987, pp. 93, 95). A space reactor colliding with such debris "may produce as many as 1,000,000 particles with a diameter of 1 millimeter or more. Some of these particles will be injected into ... regions populated by large, manned spacecraft. Even if these particles do not strike other spacecraft, they will begin to decay at an accelerated rate and reenter the Earth's atmosphere much quicker than previously calculated." Johnson and McKnight conclude that "current storage orbit practices... are insufficient to ensure the protection of continued space activities and of the Earth's biosphere in both the near term and the far term."

Beyond all questions of environmental safety, however, we believe that a ban on nuclear power in Earth orbit would have a salutary effect in restraining the weaponization of space, as discussed in my testimony.

Q5. Assuming reactors are needed to perform vital civilian and military missions, how would you modify the current reactor safety criteria?

A5. There are no vital civilian or military missions for space nuclear power. Indeed, one of the most critical problems facing the new space nuclear power programs is the absence of a defined mission for any of the nuclear power supplies now being developed.

Furthermore, the significance of the "current reactor safety criteria" is questionable. Official pledges regarding nuclear safety are not binding and are subject to withdrawal at any time, judging by the case of the "nuclear safe orbit" standard.

Granting the premises of the question, however, we would recommend establishment of an authentic regulatory process for space nuclear power. The necessity of such a process should be evident from the crisis now facing the "self-regulated" Department of Energy production reactors.

Q6. You discussed accidents involving space nuclear power. How many people have been identified as injured by these accidents?

A6. Injuries resulting from exposure to radiation are commonly categorized into prompt, or acute, effects which are produced by high radiation doses, and delayed effects, such as cancers or genetic damage, from medium or low doses.

No prompt fatalities resulted from the accidents involving space nuclear power, though some fragments of debris from the Cosmos 954 satellite were sufficiently radioactive to produce such fatalities.

The number of delayed fatalities that might have resulted, for example, from disintegration and dispersal of the U.S. SNAP 9A radioisotope source in 1964, is less clear. It is in the nature of accidental exposures to radiation that it is difficult to attribute specific cancers developed years later to a specific exposure. Instead, analysts use accident models to predict consequences, and different modelling assumptions can produce vastly different consequence estimates.

Official studies of accident consequences are often classified (improperly, in my opinion). Even when particular conclusions are released, the methodology identifying the assumptions used is generally withheld from the public. It is thus impossible to confirm or criticize them.

In any case, it should be noted that the radioactive inventory of the new nuclear power supplies will be much larger than past systems, due to their increased power level and operating time. As a result, the consequences of severe accidents in the future could be correspondingly greater.

Q7. Since it is apparent that the Soviets highly prize the RORSAT reconnaissance satellites, what evidence is there that Sagdeev is speaking for the Soviet government when he proposes banning reactors in Earth orbit? Do you know of any official contacts with the U.S. on such a proposal?

A7. Academician Sagdeev indicated that he was not speaking for the Soviet government, but that he had briefed high officials of the Soviet Foreign Ministry on the proposed ban. We are not aware of any official contacts with the U.S. regarding the proposal. We believe the U.S. should initiate such contacts.

Q8. In the NASA technology, it has been stated that reactors greatly enhance the capabilities of NASA's programs. Do you find the use of nuclear reactors for these applications acceptable? If it is acceptable for these applications, then are your concerns environmental or anti-military feelings?

A8. Nuclear power can enable NASA programs particularly in deep space, where the intensity of solar flux is too weak to provide sufficient solar power, and in lunar or Mars settlements, which could ultimately require Megawatts of power.

Such programs would not be affected by the proposed ban on nuclear power in Earth orbit.

Our concerns are both strategic and environmental. We support the proposal for a ban on nuclear power in orbit because we believe it would help to achieve two objectives: First, it would impose a technological constraint on deployment of provocative military space systems, including RORSATs and some types of SDI-type space weapons; and second, it would eliminate a recurring environmental threat.

UNIVERSITY OF CALIFORNIA, SANTA CRUZ

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PROGRAM ON NUCLEAR POLICY
ADLAI E. STEVENSON COLLEGE

SANTA CRUZ, CALIFORNIA 95064

November 10, 1988

Senator J. Bennett Johnston
Chairman
Committee on Energy and Natural Resources
United States Senate
Washington, D.C. 20510

Dear Chairman Johnston:

Enclosed please find answers to the questions transmitted to me by your letter of October 17, 1988, regarding the September 13 hearing before your Committee on "Cosmos 1900 and the Future of Space Nuclear Power." Additionally, in response to your questions near the end of the hearing about whether there was a threshold of exposure to radiation below which there was zero risk, I have addressed that matter in the attachment as well.

Since the hearing, an additional piece of information about Soviet RORSATs has been released by the Soviets. A report in Izvestiya on October 16 indicates that Cosmos-series satellites use neither the Topaz nor the Romashka reactor designs, but a subsequent design. From what is known about it, it would appear to operate at 50-100 kilowatts thermal, less than the 220 kw maximum power listed in my written testimony for the Topaz. Thus, the comparative risk of SDI reactors as opposed to the RORSATS, given in my testimony, should be increased by a factor of 2-4. Put differently, SDI reactors are 2-4 times more dangerous, relative to the current Soviet reactors, than indicated in my statement. A revised table II is attached.

It should be made clear that any views expressed in this supplement are my own alone and do not necessarily represent those of the University of California.

I should like to thank you once again for calling the September hearing, your invitation to testify, and your continued interest in this important issue. Please do not hestitate to contact me if I can be of further assistance.

Sincerely,

Daniel Hirsch

Daniel Hirsch
Director

Revised Table II

Risk Comparison, US Star Wars Reactors and Soviet RORSAT Reactor

	COSMOS-1900	SP-100 Gen. 1	SP-100 Gen. 2	Multi-Megawatt
weapons-grade uranium (kg)	~30	190	>>200	>>200
power (MW-thermal)	~.1	2.3	~23	~230-700
operating time (yrs.)	~.5	7	7	~1
relative long-lived fission product inventory	1	~300	~3000	~4500-14,000

RESPONSES BY DANIEL HIRSCH TO ADDITIONAL QUESTIONS FROM SENATOR MCCLURE

September 13, 1988 Hearing

"COSMOS 1900 AND THE FUTURE OF SPACE NUCLEAR POWER"

Question 1: Dr. Rosen of NASA has stated in his testimony that nuclear power is necessary for space exploration and expanding U.S. activities in space. Would you advocate limiting U.S. space activity efforts to avoid the use of nuclear power?

Answer: The proposal by the Federation of American Scientists and the Committee of Soviet Scientists Against the Nuclear Threat was carefully crafted to avoid impacting upon legitimate scientific and civil space missions. For example, we recognized that deep space exploration may well require the use of nuclear power because the density of solar energy decreases substantially as one gets further from the sun, making solar power not very practical as one undertakes missions to the outer planets and beyond. However, our proposed ban on the use of nuclear power by artificial satellites in **earth orbit** explicitly would not restrict **deep space** scientific missions. Similarly, nuclear power may be useful for a Moon base because of the long lunar night. Again,the proposal would not restrict such uses. Further, it recognizes that, although neither the U.S. nor the Soviets have serious plans in the near term for scientific uses of nuclear power in earth orbit, that may not be true forever. Thus the proposal bans nuclear power in orbit for a period which would not impact planned non-military uses, but leaves open a provision for review after that point if revision may be necessary because of new plans for scientific use.

It should be noted that reactors on the Moon or on probes exploring distant parts of the solar system do not pose an environmental hazard to earth, as it is the nuclear-powered artificial satellites in earth orbit that can suffer accidental reentry and release of their radioactivity.

In preparing our proposals we consulted with Dr. Rosen of NASA, and others, in order to attempt, to the maximum extent possible, to develop a plan that would provide environmental protection of the earth and restrain the militarization of space without impacting adversely on legitimate scientific missions that might require nuclear power. We believe our proposal succeeds in that regard.

For a more detailed discussion of this question I refer you to a study being performed by Professor Joel Primack as part of a series of technical studies being performed by the Federation of American Scientists, in cooperation with the Stevenson Program on Nuclear Policy at the University of California, Santa Cruz. Professor Primack has been examining potential civil uses of space nuclear power to assure that scientific uses will not be adversely affected. The results of the Primack review, as well as other studies we have performed related to space nuclear power, are scheduled to be published in the first issue of a new international journal, ***Scientific Aspects of Global Security,*** whose editorial board is composed of senior American and Soviet scientists.

Question 2: Would you support the use of nuclear reactors in earth orbit if it was beneficial to support treaty verification through surveillance spacecraft?

Answer: Surveillance spacecraft for treaty verification purposes simply do not have the power needs that would require nuclear reactors in earth orbit. We have consulted with verification specialists at the national laboratories and elsewhere and have confirmed that our proposed ban on reactors in earth orbit would have no adverse impact on treaty verification efforts.

In fact, one could argue that the proposed ban would make treaty verification easier. Academician Sagdeev noted in his written statement to the Committee that it would be easier to verify compliance with the Outer Space Treaty, which prohibits nuclear weapons in space, were nuclear materials for nuclear power purposes likewise banned. Otherwise it would be difficult to determine whether detected nuclear material in space were for bomb or power purposes. As Dr. Sagdeev noted, "Space reactors could provide potential violators the opportunity to conceal nuclear warheads in space."

Our proposed ban will in no way deter treaty verification efforts; rather, it will enhance them.

Question 3: The Soviets have a long history of using nuclear reactors in earth orbit, and will probably continue to do so. Do you propose that the U.S. should unilaterally ban reactors from earth orbit?

Answer: Our proposal is very clearly a prohibition on **both** the Soviets and Americans using nuclear reactors in earth orbit. We have explicitly called on the Soviets to abandon their nuclear-powered RORSAT program and for the U.S. to abandon its plans for very much larger reactors for Star Wars purposes.

As to the assertion in the question that the Soviets will probably continue to use reactors in orbit, that is unquestionably true unless the United States government undertakes action to push for a **bilateral** or **multilateral** prohibition. If we are concerned about Soviet use of reactors in space, the best thing our government could do would be to energetically support this proposed mutual ban.

Question 5*: Assuming reactors are needed to perform vital civilian and military missions, how would you modify the current reactor safety criteria?

Answer: The assumption is incorrect. Whereas nuclear reactors may be vital for Star Wars purposes, that is not true, as indicated in response to questions 1 and 2, for treaty verification or civilian scientific purposes in earth orbit.

Nonetheless, were the U.S. to decide not to try to control Soviet use of reactors in space and to go all-out in use of orbiting nuclear power sources for Star Wars battle stations and related devices, it would seem to me essential that the entire DOE space reactor safety criteria and procedures be changed. Currently there is an entirely unacceptable situation where DOE reactors, space reactors included, are exempt from all licensing regulations and statutes required for civilian reactors. There is no true independent oversight, no public scrutiny permitted, no binding safety regulations.

Independent experts, including critics, should be placed on INSRP, the Interagency Nuclear Safety Review Panel, that currently reviews space nuclear power in an almost "in-house" fashion. The Atomic Energy Act should be amended to require full, open, fair and unbiased adjudicatory licensing hearings for all DOE nuclear facilities, including space reactors. (This is one of the key lessons of the current debacle involving the entire DOE nuclear production complex, permitted to operate for decades unsafely because it was exempt from normal nuclear safety regulations and public licensing requirements.) All documents related to space nuclear power, including accident consequence calculations, should be made public. It is unacceptable that these are classified, creating the clear impression that hazards associated with the program are being kept from the public eye. If the SDI space nuclear power program is permitted to go forward, the so-called "nuclear safe" orbit, while insufficient to eliminate the risks of nuclear power in orbit, should be reinstated and made law.

The above changes to safety practices would not in any fashion eliminate the risks of nuclear power in orbit; our proposed ban is the only policy that would do that.

---

*Note: Question 4 was directed to Mr. Aftergood alone.

Question 6: You discussed accidents involving space nuclear power. How many people have been identified as injured by these accidents?

Answer: Estimates of the number of cancers, leukemias, and genetic effects induced by the burnup of the plutonium-238 from the U.S. SNAP-9A accident or the reentry of the Soviet COSMOS-954 and COSMOS-1400 require complex modeling assumptions related to particle size, atmospheric transport, dose factors for uptake of radionuclides into agricultural products and for ingestion and inhalation into people, as well as from ground shine, coupled with very controversial and widely ranging dose-response-curve assumptions for induction of health effects from various levels of radiation. Because much of the documentation supporting US contractor estimates of space nuclear power risks remains classified, independent review has not yet been possible, so a reliable answer quantifying casualties is not yet possible. I hope your Committee will arrange for **all** the documentation from **all** U.S. studies of potential consequences from past launches of space nuclear power sources, U.S. and Soviet, as well as for potential SDI reactors, to be released for that kind of independent review to be made possible.

What can clearly be said is that whatever the consequences from past accidents, accidents involving US Star Wars reactors could produce consequences several hundred to more than 10,000 times as great as the worst possible accident involving past or current space reactors. (See Revised Table II from my testimony). That is why it is so important that this matter be reassessed before crossing that much more dangerous threshold.

Question 7: Since it is apparent that the Soviets highly prize the RORSAT reconnaissance satellites, what evidence is there that Sagdeev is speaking for the Soviet government when he proposes banning reactors in Earth orbit? Do you know of any official contacts with the U.S. on such a proposal?

Answer: It is true that the Soviets highly prize the RORSATs. Nonetheless, I was given a clear signal from the Soviet Foreign Ministry that they were prepared to **seriously discuss** giving up the nuclear-powered RORSAT in the context of a bilateral agreement to ban nuclear reactors in orbit, were the U.S. to initiate such discussions. This was by no means a commitment as to what their position would be in such discussions, were the U.S. to initiate them, but rather a clear statement of willingness to discuss with the U.S. such a ban or other solutions to the space nuclear power problem. I asked if I could communicate this to the U.S. government and was told I could.

Shortly after my return from Moscow I briefed the State Department about what I learned in Moscow, both about COSMOS-1900 and prospective Soviet responses should the U.S. initiate discussions about a potential ban.

I should make clear that the proposal is not coming from the Soviet government, but was essentially a proposal by the Federation of American Scientists that Academician Sagdeev and his Committee of Soviet Scientists have concurred in. Academician Sagdeev made clear in his written statement to your Senate Committee that he was not speaking on behalf of the Soviet government but for himself and the Committee of Soviet Scientists.

I believe the indications are clear, however, that the Soviet government would consider very seriously any suggestion for a mutual ban on reactors in orbit, were the U.S. to commence such discussions. The only way to find out whether they would officially support such a mutual ban is to initiate bilateral discussions. I strongly recommend that the Senate urge the new Administration to initiate such discussions; or for the Congress to find some legislative vehicle to attempt to put such a bilateral ban into effect.

Answers by Daniel Hirsch to Supplemental Questions/ Page 8

Question 8: In the NASA technology, it has been stated that reactors greatly enhance the capabilities of NASA's programs. Do you find the use of nuclear reactors for these applications acceptable? If it is acceptable for these applications, then are your concerns environmental or anti-military feelings?

Answer: As indicated in previous answers, NASA programs for which there are serious plans and which would require reactors would be untouched by our proposed ban because they are interplanetary missions or a Moon base. Such missions do not pose the environmental risks associated with reactors in earth orbit, as contemplated by SDI.

It has recently been disclosed that orbiting reactors actually interfere with important space scientific missions, particularly gamma ray astronomy efforts. This disruption occurs as a result of inteference with sensitive equipment due to interactions from the gamma rays and positrons emitted by operating space reactors. Spurious readings have already obstructed civilian science missions. Thus, a ban on reactors in orbit could, to that extent, actually enhance space science efforts.

Our proposal would protect the environment and restrain the militarization of space while retaining the option of using nuclear power for those legitimate scientific missions where it may be essential and where it cannot pose a major risk to the earth environment.

Supplemental Matter: Near the end of the September 13 hearing Senator Johnston asked some questions about whether there was a threshold of exposure to radiation below which there was zero risk.

Response: I note that the New York Times of October 29, 1988, reports that the U.S. government has conceded in court documents filed in early October in Federal Court in Cincinnati that there is no safe threshold and that "any amount of unnecessary radiation exposure, however small, carries with it some increased risk of adverse health effects." This has long been the widely accepted view among almost all experts in the field of radiation protection, and has been the presumption of all official radiation safety bodies, both domestic and international.

In consultation with my colleague, Dr. Roland Finston, head of Health Physics and Radiation Safety at Stanford University, I am reminded that all experiments to date of sufficient size to produce a demonstrable effect from extrapolation from high dose experience have borne out the absence of a threshold. Although there could still be a threshold below the levels tested, experiments to prove it do not exist and would be unacceptably large.

Absence of a threshold has been shown to go down to a few rads. The theoretical models for genetic mutation and cancer induction would support the premise of lack of threshold. One of the leading models for such induction is that it is induced by single errors in genetic code, essentially done by breaking a single chemical bond, which can be done by a single ionizing event. Thus, risk from radiation is a function of probability that a certain number of ionizing events from a certain level of ionizing radiation will cause that damage. Society must make determinations about the risk level acceptable to society but it cannot at present be presumed that any amount of radiation involves zero risk.

All established institutions that have assessed the threshold issue--e.g., the International Commission on Radiation Protection, the National Commission on Radiation Protection, and the National Academy of Sciences-presume for radiation safety purposes that there is no "safe" threshold. The ALARA philosophy, of keeping radiation exposures "as low as reasonably achievable," is driven by the assumption that there is no demonstrable threshold.

Answers by Daniel Hirsch to Supplemental Questions/ Page 8

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APPENDIX II.—ADDITIONAL MATERIAL SUBMITTED FOR THE RECORD

GENERAL ELECTRIC
COMPANY
1331 PENNSYLVANIA AVENUE, N.W.
SUITE 700
WASHINGTON, D.C. 20004

TINA BEACH

October 12, 1988

Mr. Jim Bruce
Senior Counsel
Senate Energy Committee
364 Dirksen Senate Office Building
Washington, DC 20510

Dear Jim:

In response to Senate Johnston's suggestion, GE has prepared an assessment of the limitations of the linear dose response methodology for cancer detection. Charles Schmidt has sent a copy to the Senator under separate cover. We appreciate this opportunity further to explain this complex issue.

Sincerely,

Tina Beach

/flg

SENATE ENERGY AND NATURAL RESOURCES COMMITTEE
HEARING ON NUCLEAR POWER IN SPACE
WITH CHAIRMAN J. BENNETT JOHNSTON, (D-LA)

RESPONSE TO SENATOR J. BENNETT JOHNSTON'S QUESTION TO GENERAL ELECTRIC

This brief addresses Senator J. Bennett Johnston's request for General Electric's assessment of the shortfalls or limitations of the linear dose response methodology for estimating radiation induced cancers at low dose levels. In addition, this brief provides our assessment of the safety consequences of a postulated accident resulting in severe damage to an orbiting SP-100 reactor.

This assessment responds to charges that accidents in space orbit resulting from impacts of space debris would cause severe damage to an SP-100 and result in extensive radiation exposure to the earth's population and would lead to thousands of latent cancer fatalities.

The linear methodology for calculating radiation induced health effects at low dose levels doesn't make sense.

It has become common practice in nuclear work to limit radiation doses to levels as low as reasonably achievable. For the purposes of establishing very conservative limits, a methodology has evolved that implicitly assumes that there is no safe level of radiation exposure and that harmful effects are linearly proportional to dose. Thus, if a high radiation dose to a single individual is known to cause latent cancer death it is assumed that the same dose equally divided among many people will still cause one latent cancer death, no matter how small the dose to each person.

The weakness of this methodology is more easily seen when applied to the use of everyday medication. For example if a single person ingests 100 aspirin tablets it is probable that person will die. However, if that same dose of aspirin is divided among 100 people, one aspirin per person, no one is likely to die. If the same 100 aspirin were divided among one million people the likelihood of any aspirin induced death is even smaller, because the doses, while real, are extremely small. The linear methodology however, would assume that one death would occur no matter how small the aspirin dose.

It is evident from this example, that the linear methodology just doesn't make sense at low dose levels for aspirin. Why should it make sense for low dose levels of radiation, particularly at dose levels well below the levels we receive every day from naturally occurring phenomena? The answer is the linear methodology doesn't make sense for radiation either.

For example, using the linear methodology, the Environmental Protection Agency has estimated that 5000 to 20,000 people in the United States will die from radon induced lung cancer each year. Naturally occurring radon is radioactive and exists in varying degrees in all homes and buildings.

This calculated death rate however, is refuted by real data. Both Sweden and Finland have high average national radon concentrations, but lung- cancer rates for women in each of these countries are below the average for industrialized countries. In one part of Finland radon levels are eight times the world average and three times the national average, yet lung-cancer rates in women are less than the Finnish national average. These data are from a recent study completed by Dr. Bernard Cohen who has provided much of the data on radon concentrations in the American home.

Cohen has said that this new study implies there is a threshold dose for radon below which there is no health risk, and that low doses may even trigger the human immune system to provide protection against radiation induced cancers. If this is true for radon it is true for all radiation.

The scientific community cautions about use of linear dose extrapolations

To add to this common sense analysis, it should be noted that The National Council on Radiation Protection and Measurements (NCRP) has warned against using the linear dose response evaluation to set policy: "The NCRP wishes to caution governmental policy-making agencies of the unreasonableness of interpreting or assuming 'upper-limit' estimates of carcinogenic risks at low radiation levels derived by linear extrapolation from data obtained at high doses and dose rates, as actual risks, and basing unduly restrictive policies on such interpretation or assumptions". The NCRP has recommended (Report No. 91) a threshold level, that it calls the Negligible Individual Risk Level (NIRL), below which efforts to reduce radiation exposure of an individual are unwarranted. The NIRL corresponds to a dose rate of 1mRem/yr.

Consistent with NCRP recommendations, the United States' Interagency Nuclear Safety Review Panel (INSRP) has encouraged use of a threshold of 1mRem/yr for Radioisotope Thermal Generator Safety Analyses. Populations exposed to this dose rate or less, are identified as having no health effects. This value is equally appropriate for use in SP-100 safety analysis. Using the INSRP threshold, the analysis shows that no cancers would result from a severe SP-100 accident in orbit.

SP-100 has less than one chance in ten thousand of experiencing a severe accident in orbit

The postulated accident scenario upon which the above estimated health effects are based is discussed in the remainder of this brief.

As provided in Department of Energy and General Electric testimony at the hearing, SP-100 has several engineered safety systems that would make the possibility of severe damage very unlikely. There is a small chance that an orbiting SP-100 will be impacted by a piece of space debris. Protection is provided based on current best estimates of future debris environments to assure a high probability of mission success even if some impacts by meteoroids and small debris particles occur.

A small chance remains that a high energy piece of debris might cause a loss of reactor coolant. A backup cooling system has been incorporated into SP-100 to mitigate the damage from this event. The backup coolant system would assure that most fission products are retained in the fuel and the reactor would retain structural integrity that would permit permanent disposal operations to be completed.

For more severe damage to occur requires larger pieces of debris with energy sufficient to damage both the reactor coolant system and the backup coolant system. The probability of severe damage from such an event is estimated to be less than one chance in 10,000 in its operating life (10 years) even when SP-100 is operating in an orbit containing the peak levels of debris forecasted for 1995.

The released radioactivity will naturally decrease to safe levels before reaching the earth's surface

We have estimated the health effects of a large debris impact that releases all of the gaseous fission products, and 10% of the solid fission products and fuel in SP-100. More realistically, much of this radioactive material would condense and freeze on parts of the reactor and satellite structure and be retained in orbit. We have not taken credit for this effect.

The released radioactive gases and submicron particles would expand into space under the influence of natural forces such as micro-gravity, solar wind and Brownian motion. The expansion would result in dilution of the released material and motion toward the earth's surface. Transport of all this radioactivity toward the earth would take up to 10 years.

The exact transport time is not too important because the radioactive elements tend to have decay half lives that are very short relative to the transport time or very long relative to the transport time. The very short half-life materials that constitute a large fraction of the radioactivity decay away before reaching earth. The long half-life materials, that are a much smaller fraction of the inventory, do not decay to any great extent. Table 1 lists the estimated amount of radioactivity that reaches the earth.

The radioactivity that finally reaches the earth would be far below natural background levels. Table 2 summarizes the calculated doses. These levels are one hundred thousandth to one millionth of the exposure that every individual on earth would experience from natural background radiation during the same period. As discussed at the beginning of this brief these extremely low doses would be far below the safe threshold.

SP-100 accidents in space do not present a significant risk

The hypothetical accident evaluated here is one of the more severe accident scenarios that can be postulated as the result of debris impacts in orbit. Other scenarios have been postulated and evaluated in our comprehensive risk analysis. In general, the contribution to the overall risk from other debris-impact caused accidents is comparable to or less than the scenario evaluated here and supports our assessment that SP-100 will be safe.

TABLE 1
ESTIMATE OF RADIOACTIVITY IN THE ATMOSPHERE FOLLOWING A HYPOTHETICAL SEVERE REACTOR ACCIDENT IN A 100 KWe SP-100

ISOTOPES	INVENTORY REACHING EARTH (1) CURIES
Kr	1040
Kr85m	0
Kr83m	0
Kr87	0
Kr88	0
Kr89	0
Xe 131m	0
Xe 133m	0
Xe 133	0
Xe 135m	0
Xe 137	0
Xe 138	0
I 131	0
I 132	0
I 133	0
I 134	0
I 135	0
Sr90	13200
Cs 137	14300
Cs 134	45
Y90	13200
Sb 125	164
Ce 144	14
Pm 147	2740
Sm 151	410
Ev 155	164
U 234	9.4
U 235	0.3
U 236	0.1
Th 231	0.3
Pu 238	3.9
Pu 239	1.1

(1) See assumption in text concerning radioactive released in orbit and transport to earth. Inventory is spread over large fraction of earth's atmosphere.

TABLE 2
INDIVIDUAL DOSE FROM A HYPOTHETICAL SEVERE REACTOR ACCIDENT IN A 100 KWe SP-100, MILLIREM (1)

		SKIN	BONE	LIVER	TOTAL BODY	THYROID	KIDNEY	LUNG	GI-LLI
INGESTION PATHWAY	MILK	-	4.2E-5	1.3E-7	1.6E-3	5.4E-9	8.6E-4	2.9E-4	5.1E-4
	MEAT	-	5.5E-7	1.6E-9	4.7E-4	2.2E-7	2.5E-4	8.1E-5	2.3E-4
	PRODUCE	-	1.2E-5	3.6E-8	1.6E-3	5.1E-8	8.4E-4	2.8E-4	5.0E-3
INHALATION PATHWAY		-	2.7E-2	1.9E-4	1.8E-3	2.E5-9	7.7E-5	2.7E-3	2.0E-4
EXTERNAL CLOUD		1.6E-2(2)	-	-	-	-	-	-	-

(1) CUMMULATIVE DOSE DURING 50 YEAR EXPOSURE (2) EXAMPLE. 1.6E-2 = 0.016

F.A.S.

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•Nobel laureates

30 January 1989

James T. Bruce
Senior Counsel
Committee on Energy and Natural Resources
United States Senate
Washington, D.C. 20510-6150

Dear Mr. Bruce:

As per your letter of January 5, please find enclosed my response to the claims by General Electric that there exists a "threshold" below which radiation doses are not dangerous, or perhaps even beneficial. Because of the importance of this issue, I was assisted by my colleague, Dr. Roland Finston, Chief of Health Physics and Radiation Safety at Stanford University, whose input is attached.

Please let me know if I can be of further assistance. For the next few months I can be reached at the above address.

Sincerely,

Daniel Hirsch

Daniel Hirsch

enclosures: as stated

National Council Members
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Bruce Blair
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30 January 1989

RESPONSE TO CLAIMS BY GENERAL ELECTRIC OF A "THRESHOLD" BELOW WHICH RADIATION EXPOSURES TO HUMANS ARE NOT DANGEROUS OR PERHAPS EVEN BENEFICIAL

Prepared by Daniel Hirsch
Federation of American Scientists

at the request of
Senator J. Bennett Johnston
Chairman
Senate Energy and Natural Resources Committee

Introduction

At the September 13, 1988, hearing on the risks of space nuclear power, called by the Senate Energy and Natural Resources Committee, a representative of the General Electric Company, the prime contractor for the SP-100 space reactor, asserted that there was a threshold of radiation exposure below which there was no risk to human health. The GE representative criticized U.S. governmental agencies and the nuclear industry in general for ignoring the existence of a "safe threshold level," and "for conservative reasons" designing accordingly.

Chairman Johnston requested a written statement by GE explaining why the official government and industry methodology regarding radiation risk is, in the opinion of GE, flawed, and invited the response of two independent witnesses who had testified at the same hearing. What follows is the response by one of those witnesses.

The Aspirin Analogy

GE attempts to dismiss the existence of any risk whatsoever from low doses of radiation by analogy to risks associated with consumption of very large quantities of aspirin. GE states that consumption of a large number of aspirin tablets by one person would probably result in that person's death, but that if a large number of people consumed one tablet each, it is likely no one will die. From this GE concludes that if a large radiation dose is divided into many much smaller doses and distributed among many people, there will be no negative health effects among any of those people. This analogy is faulty and the resulting conclusion incorrect.

Radiation is not aspirin. The somatic insult from ionizing radiation is different from the chemical toxicity of a substance such as aspirin. Whereas there are amounts of chemicals which, if ingested, will poison a person, and below which, will not, the same is not true for the carcinogenic and mutagenic properties of radiation. GE here confuses poisoning with induction of latent cancers and genetic defects.

Two Forms of Radiation Injury: Acute and Latent

There are two primary forms of injury from exposure to varying levels of radiation: acute injury and latent. Put differently, high levels of radiation can produce prompt death through radiation "poisoning," while lower levels elevate the risk of delayed effects such as cancers and leukemias in the exposed individuals and genetic deformities in their offspring. At approximately 450 rems, half of the population so exposed will die within 30 days from radiation poisoning--the kind of ghastly deaths faced by people at Hiroshima and Nagasaki within days to weeks of the atomic bombings. At higher levels, the percent that will die rises, soon reaching 100%; at somewhat lower levels, the percent shrinks, indeed reaching a threshold of some tens of rems where prompt casualties are not expected.

However, that does not mean that latent somatic insults have not been incurred which can result in delayed health effects at these lower doses. Indeed, the Hiroshima and Nagasaki data clearly show that such doses produce delayed health effects. Within a few years of the bombings, long after the acute casualties had ceased occurring, a substantial increase in the incidence of leukemias occurred; since then, significance increases in the incidence of cancers of various sorts have occurred, and are still occurring, more than forty years later.

Furthermore, the likelihood of dying from a radiation-induced cancer or leukemia is clearly related to the magnitude of the exposure received. In general, the further from the epicenter of the explosion, and thus the gamma and neutron burst, the lower the probability of coming down with cancer or leukemia. When other factors are included, such as shielding, exposure correlates well with delayed health effects, although there has been some debate about the shape of the correlation (e.g., linear, linear-quadratic, etc.).

No Established Radiation Protection Body Has Accepted the Existence of a "Safe" Threshold

No respected national or international radiation protection body, despite implications to the contrary by GE, has accepted the idea of a threshold for delayed health effects. I note that the GE statement is somewhat misleading in this context. It quotes a statement by the National Council on Radiation Protect and Measurements (NCRP), which warns simply that assuming a linear shape to the dose-response curve may be unduly conservative (a matter subsequently shown not to be the case by the revised Hiroshima data). The NCRP statement quoted does not say that there is a threshold below which no risk exists.

Similarly, GE rather misleadingly characterizes as acceptance of a safe threshold the NCRP recommendation of a "Negligible Individual Risk Level" below which efforts to reduce radiation exposure of an individual are supposedly unwarranted on a societal cost-benefit basis. This proposal is merely for what is generally called a "de minimus" criterion, which assumes, not that there is no risk below a certain level of exposure, but that the risk is small enough to be sufficiently negligible as to not be worth the cost of reducing the exposure further. This proposal--which is controversial--nonetheless is not acceptance of a threshold below which damage does not occur but is rather an attempt to establish a level of damage which is socially "acceptable." I note further that the proposal, as described by GE, is for doses to an individual, not population doses. It is the latter which concerns GE, because an accident involving one of their SP-100 reactors could expose extraordinarily large numbers of people globally to radioactivity, resulting in high population doses.

I should also note that the practice of the US Interagency Nuclear Safety Review Panel of ignoring doses below 1 mRem/year for plutonium space power source safety analyses, even if the doses occur in hundreds of millions of people globally, has been subject of some criticism, going against the longstanding health physics ALARA requirements. This INSRP practice appears to be one further reason why INSRP should be expanded to include independent experts, and not be merely an in-house review.

The New Hiroshima Data Suggest Radiation Substantially More Dangerous Than Previously Thought

Recently, a major error has been discovered in the dosimetry assigned to Hiroshima victims. Basically, there now appears to have been far less neutron irradiation than previously assumed, meaning that the subsequent cancers were initiated by the gamma radiation alone, making gamma exposure considerably more dangerous than previously thought. Furthermore, the new data suggest that the shape of the dose-response curve is indeed linear, not the less dangerous linear-quadratic that some had hoped for. Estimates of how the various new findings will increase our understanding of radiation risks range upwards of 5-15 times higher than past ICRP estimates. (For an excellent discussion of how the new data are substantially revising upwards our assessment of the dangers of "low" levels of ionizing radiation, see former Manhattan Project physicist Joseph Rotblat´s article, "A Tale of Two Cities," in the New Scientist of 7 January 1988.)

Furthermore, a new health effects model being prepared by John Evans of the Harvard School of Public Health for the U.S. Nuclear Regulatory Commission as input into the NRC´s MACCS accident consequence code similarly shows that radiation risks may be substantially higher than previously thought, given a range of new data. In short, the assessment by the scientific community of risks from radiation exposure is resulting in substantially increased risks, not the other way around. (I should add that the recent claims of evidence by Bernard Cohen, cited by GE, that radon exposure is not harmful and may even be good for you, have been greeted with considerable skepticism in the scientific community.)

Other GE Assertions

I have not been asked to provide a detailed response to the rest of GE´s statement, which makes such claims as that their SP-100 reactor "has less than one chance in ten thousand of experiencing a severe accident in orbit." Suffice it to say that I believe such assertions are unsupported, factually in error, and would appear to be, given GE´s interest in the SP-100 project, somewhat self-serving.

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January 30, 1989

Dear Mr. Hirsch:

In response to your request for an explanation as to why the linear dose-response extrapolation is not flawed as applied to cancer induction or gene mutation, and why the aspirin analogy presented by Mr. Charles A. Schmidt of General Electric is flawed, let me offer the following:

The aspirin analogy is flawed because it is applying what is true for a chemical poisoning to a phenomenon which is in all likelihood atomic in origin. There are examples of radiation effects which have a threshold, such as reddening of the skin, loss of hair, gastro-intestinal and bone marrow acute damages; and these are correctly compared to the aspirin model because they involve sufficient amounts of cell killing or sterilization to the point where the tissue cannot survive the injury. The extent of the injury is proportional to the dose, for these examples.

In contrast, there are effects of radiation which are believed to require the injury of only a single cell, where the injury, rather than killing or preventing the cell from dividing, causes a modification in the chemical instructions of the cell (DNA) so that it divides abnormally or produces abnormal chemicals. The extent of the injury is constant, the likelihood of its occurence depends on dose.

The process of DNA modification is also known as mutation and can occur in the reproductive cells (genetic) or the balance of the cells of the body (somatic). The issue of whether there is or is not a threshold for cancer was addressed by a Working Group reporting to the National Institutes of Health in 1985 (NIH Publication No. 85-2748). These experts on radiation and cancer wrote:

> "For carcinogenesis, in general, and radiation carcinogenesis in particular, there are strong grounds for questioning the assumption that the dose-response relationship has a threshold (4,6,56-59). The evidence that many, if not most, cancers arise from a single cell (60), the putative role of DNA or chromosomal damage in carcinogenesis (61-66), the heritable nature of the neoplastic transformation in somatic cell lines, and the linear-nonthreshold nature of the dose-effect relationship for radiation-mutagenesis and chromosome aberration induction the the low-dose region (6,67) imply that radiation-induced damage to the DNA or to the chromosomes of a single cell may, under certain conditions, exert a potentially carcinogenic stimulus, even at the lowest radiation exposure level."

There are several possible non-threshold models to relate dose to the risk of cancer and heriditary illness. The linear model is not the most conservative, by the way, for there are proponents of models on either side of that line. Few, if any, experts would argue for a threshold model. The NIH working group explored the non-threshold models succinctly and concluded that the linear model should be applied to cancer of the breast and thyroid and the linear-quadratic model to all other cancer sites. Nowhere in their analysis did they validate the threshold model of Mr. Schmidt.

Mr. Schmidt's analysis of radon is unfortunately a bit too optomistic. It has been long recognized that there are differences between the dose-effect relationships for low density radiations (x-, beta, and gamma rays) and high density radiations (alpha and neutron rays). So that even if Dr. Cohen's data should be accepted as showing a threshold for radon and lung cancer, it would be a far cry from proving the general case of hormesis for all radiation in all tissues of the body.

Dr. Schmidt's invocation of the Negligible Individual Risk Level (NIRL) as synonymous with no health effects belies the NCRP's specific statement that the risk at the NIRL is nonetheless 1 chance in 10 million. There are those who would question the exact numerical value of that risk estimate, but most experts would not accept the value "0" as prudent for public health purposes. Nor did the NCRP claim there was no risk at the NIRL level; rather that compared to other risks of life, such a low dose can be dismissed from consideration. The ultimate decision as to the acceptability of risk when a possible radiation exposure is society-wide would ethically be delegated to that society or its elected representatives. Only by slight-of-word it can it be defined as zero.

Sincerely,

Roland A. Finston

Roland A. Finston, Ph.D.

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James T. Bruce
Senior Counsel
Committee on Energy and Natural Resources
United States Senate
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January 30, 1989

Dear Mr. Bruce:

Thank you for sending me the General Electric (GE) statement concerning the linear dose response methodology for estimating radiation-induced cancers at low dose levels.

Since I believe the GE statement is in error, I would like to take advantage of the opportunity offered by Chairman Johnston to reply to it. My response is attached.

Yours sincerely,

Steven Aftergood
Executive Director

REPLY TO THE GENERAL ELECTRIC STATEMENT ON LINEAR DOSE RESPONSE

Steven Aftergood
Committee to Bridge the Gap

The assertion by General Electric (GE) that there is a threshold dose level below which radiation is safe is almost certainly wrong, because of the way that radiation is absorbed by human tissue (see below). Furthermore, the GE position has neither been demonstrated empirically nor is it generally accepted.

*

General Electric argues convincingly that the linear methodology does not apply to medications such as aspirin. If a single person consumes 100 aspirin tablets in a short time, it is probable that person will die. If, however, 100 people each consume one aspirin tablet, it is unlikely that any deaths will result. There is, clearly, a safe threshold dose for aspirin.

But GE errs in supposing that radiation exposure is analogous to the ingestion of aspirin. It is not. The carcinogenic effects of radiation exposure result from damage to individual cells, and such damage can occur even at very low overall doses. This is because radiation energy is deposited "stochastically." When an organ or body part is exposed to radiation, the energy is not evenly distributed: some individual cells absorb relatively high amounts of energy, others absorb lower amounts. (The dose that we measure is the average energy deposited over the entire organ.)

And in the words of Dr. David J. Brenner(1), "The random nature of energy deposition at the cellular level implies that, for some number of cells, any energy deposition threshold will be exceeded, no matter how low a total dose is absorbed by the system as a whole."

Thus, even at a very low overall dose, some individual cells will inevitably receive the energy equivalent of a much higher average dose that is clearly capable of producing cellular damage.

Unlike the case of aspirin, it is important to be concerned about the effects of radiation on individual cells because most cancers are monoclonal in origin-- that is, they can begin with damage to a single cell.

Given the way that radiation energy is deposited in human tissue, and the potential importance of damage to individual cells, the assumption of a safe threshold dose does not "make sense."

The fact that radiation-induced effects are possible at any low dose does not necessarily imply that radiation dose response must be precisely linear(2). But in the absence of more complete data, the linear dose response methodology is a reasonable and appropriate model to use.

*

General Electric refers to a recent study by Dr. Bernard Cohen that shows a negative correlation between average levels of radioactive radon in certain regions and incidences of lung cancer. (In other words, fewer lung cancers were reported in some areas with relatively high average radon levels than in some other areas that have lower average radon levels.) Some, including GE, have inferred from this that there must in fact be a safe threshold dose of radiation.

This inference has not won general favor, however. The U.S. Environmental Protection Agency has suggested that while Dr. Cohen's work "warrants more investigation," his findings "might have been skewed by confounding factors-- influences not related to radon risks, like differences in smoking rates or in the amount of time people spend in their homes."(3)

Since this is not a purely abstract or theoretical question, but one that bears directly on policy decisions affecting public safety, the burden of proof must clearly lie on those who are trying to lower the estimates of public health impact (an effort that usually precedes an attempt to increase the actual impact). That burden has not been met to date.

Responding to Dr. Cohen's radon study, Dr. C. Richard Cothern of the U.S. Environmental Protection Agency stated recently(4):

"It is certainly true that no one knows whether there is a threshold of radon [or other radiation] exposure, below which there is no hazard."

"Unless and until we know that there is a threshold hazard level, it is prudent to assume that even the smallest amounts of radon [or other radiation] are dangerous."

*

I find GE's analysis of the risks of an accident in orbit involving the SP-100 to be cursory and unconvincing, even beyond the false assumption of a safe threshold dose. But since this subject goes beyond the Chairman's question on the linear dose response methodology, I will refrain from further comment on it here.

NOTES

1. Radiation Research, vol. 116, pp. 172-174 (1988). Emphasis in original. I have also relied on the same author's Letter in New Scientist, 22 October 1988, p. 76. Dr. David J. Brenner is Assistant Professor of Radiation Oncology at the Radiological Research Laboratory, College of Physicians and Surgeons of Columbia University, New York. I am indebted to him for reviewing with me his thoughts on this subject.

2. Indeed, there is evidence that for some levels and types of radiation, the dose response is supralinear. This means that the linear dose methodology would underestimate the actual response. See John W. Gofman, Radiation and Human Health, Updated and Abridged Edition, Pantheon Books, New York, 1983, pp. 226-232, and literature cited therein.

3. Malcolm W. Browne, "Scientist Says Government May Exaggerate the Danger of Radon in Homes," New York Times, September 28, 1988.

4. ibid. Dr. Cothern is Executive Secretary of the Environmental Health Committee of the U.S. Environmental Protection Agency. Bracketed words added by S.A.

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